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Flight-Vehicle Structures Education in the United States—Assessment and Recommendations

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SUMMARY

An assessment is made of the technical contents of flight-vehicle structures curricula at 41 U.S. universities with accredited aerospace engineering programs. The assessment is based on the technical needs for the new and projected aeronautical and space systems as well as on the likely characteristics of the aerospace engineering work environment. A number of deficiencies and areas of concern are identified and recommendations are presented for enhancing the effectiveness of flight-vehicle structures education. A number of government supported programs that can help aerospace engineering education are listed in the appendix.

1. INTRODUCTION

Significant and far-reaching advances have been made in the last few years in aeronautical and space technologies. In space, the National Space Transportation System (NSTS) is expected to be fully operational before the end of the present decade. The shuttle (after completing design modifications) will serve as the core element, and will be complemented by large- and medium-sized expendable launch vehicles (ELV's). The key elements for the space transportation architecture beyond the mid 1990's have been identified by NASA and DoD, under the National Security Decision Directives (NSDD-144 and NSDD-164), to include an unmanned cargo vehicle, a new manned vehicle, a new reusable orbital transfer system, orbital maneuvering vehicles, and innovative launch and flight operations approaches. New technologies have been developed and used in space-robotics, automation and in-flight maintenance. Greater computational capabilities are now available.

In aeronautics, new technology thrusts have been launched to assess potentially powerful aircraft technologies such as forward-swept wing, advanced turboprop engine, and supersonic and hypersonic flight vehicles. These new technology thrusts will support the development of future commercial and military aircraft.

The importance of aeronautics and space technologies to national progress and achievement is manifested by: 1) commitments made to build a permanently manned space station within a decade, and to develop a MACH 25 hypersonic vehicle, the National Aerospace Plane (NASP). The hypersonic commercial transport version of NASP is commonly referred to as the Orient Express; 2) the launching of the Strategic Defense Initiative (SDI); 3) the development of a commercial space policy; and 4) the establishment in March 1985 of a National Commission on Space to identify the civilian space goals for the next fifty years. The final report of the Commission (Ref. 1) recommended the creation of a basic transportation infrastructure to open broad access to new lands, and the establishment of human settlements on the moon and on Mars. These programs will open the door to space exploration for scientific inquiries, commerce and national security.

Since much of the basic research in aeronautics and space, as well as the training of scientific and engineering manpower, is performed within the university system, the major resurgence of aeronautics and space technologies is providing the academic community with potential opportunities for creative work, as well as with problems and challenges. The problems stem from: a) the dramatic increase in the undergraduate aerospace engineering enrollment; b) the decline in the number of advanced degrees in aerospace engineering in the past few years; and c) the rapid obsolescence and

deterioriation of engineering laboratory equipment and facilities. The challenge is whether current aerospace engineering degree programs are adequate for meeting future needs in aeronautical and space technologies. Needless to say, the future of aviation and space exploitation depends to a great extent on maintaining high quality university programs.

The concern for the adequacy and quality of aerospace engineering education, and engineering education in general, has prompted a number of studies in recent years. The results of these studies are contained in a number of publications, including a report on the education and utilization of engineers (Ref. 2), an assessment of research-doctorate programs in engineering (Ref. 3), a National Research Council report on engineering education and practice in the U.S. (Ref. 4), an AIAA survey on ABET-accredited aerospace-type programs (Ref. 5), an AIAA report on the crisis in engineering education (Ref. 6), an assessment of NASA-universities relationships in aero/space engineering (Ref. 7), and the reports by the American Society of Engineering Education on repositioning engineering education to serve America's future, and on Quality of Engineering Education (Refs. 8, 9 and 10). Except for Ref. 5, which listed the courses in each program, all the cited reports did not address the technical contents of the aerospace engineering curricula. The present study is a first attempt at assessing the technical contents of current aerospace engineering programs. Specifically, the objectives of this report are to:

a) assess the current status of flight-vehicle structures education at U.S. universities

b) identify the needs in order to meet the challenges of future aeronautical and space vehicles

c) present recommendations for increasing the effectiveness of flight vehicle structures education

The organization of the present paper is as follows: Sections 2 and 3 give some background material pertaining to the trends in the number of aerospace and total engineering degrees granted by U.S. institutions, and the new and projected aeronautical and space systems. Also, some of the technical needs in the materials and structures areas are identified and the likely characteristics of the future aerospace engineering work environment are outlined. In Section 4 an analysis is given of the flight-vehicle structures curricula at 41 U.S. institutions, and the areas of concern in these curricula are identified. Then in Section 5 the goals of aerospace engineering programs and the three key elements of these programs, namely, the delivery system, the role of the faculty and the role of the computer, are discussed. In Section 6 a number of recommendations are given for increasing the effectiveness of flight-vehicle structures education. The current government supported programs that can benefit flight-vehicle structures and aerospace engineering education in general are summarized in Appendix I. It is hoped that the present study can be used as a model for assessing other technical disciplines within the aerospace engineering programs.

2. TRENDS IN AEROSPACE ENGINEERING DEGREES

The concern for the quality of aerospace engineering education may be attributed to a number of factors including: a) dramatic increase in undergraduate enrollments in recent years; b) decline in the number of advanced degrees in the same period; c) faculty shortages - the increase in the number of faculty has not been commensurate with

undergraduate enrollment increases; d) inadequacy of course contents, resulting from a rapidly expanding and changing knowledge base; and e) aging and outmoded laboratory equipment and instrumentation. As a background to the first issue, the historical factors affecting the changes in the number of aerospace engineering degrees as well as the total number of engineering degrees are discussed in this section. The other three issues are addressed in a later section.

Figure 1 shows the number of aeronautical and aerospace engineering degrees awarded from U.S. universities since 1950. The increase in the number of B.S. degrees from 1954 to 1960 was due to the increasing demand for aeronautical engineers through the early 1960's. The buildup in space activities increased this growth rate as professional degrees in aerospace and astronautical engineering were added. The golden age of space technology occurred around the mid 1960's, and is reflected in the peak of B.S. degrees granted in 1970 (2756 B.S. degrees granted that year). The number of M.S. and Ph.D. degrees reached their maximum values in the same period (841 M.S. degrees in 1968 and 217 Ph.D. degrees in 1971). This golden age was followed by a period of explosive decompression which lasted until the mid 1970's. The number of B.S. degrees reached their minimum of 1009 in 1976. Then by the mid 1970's a careful buildup of aerospace programs took place. A very rapid increase in undergraduate enrollments has occurred since the late 1970's resulting in a dramatic increase in the number of B.S. degrees awarded since the early 1980's. Current projections are that this trend will continue through the 1980's.

It is useful to correlate the trends in aerospace engineering degrees with those of total engineering degrees. Figure 2 shows the total number of engineering degrees awarded by U.S. universities since 1950, and Figure 3 shows the ratios of the aerospace engineering to the total engineering degrees. As can be seen from Figure 2, there has been a dramatic increase in the number of B.S. degrees in the late 1970's and early 1980's which may be attributed to: a) positive student attitudes toward engineering since the mid 1970's; b) increase in the number of minorities and foreign nationals in engineering programs; and c) improved engineering job market. Since the early 1980's there has been an increase in the number of M.S. and Ph.D. degrees awarded by U.S. universities. However, the increase in the number of advanced degrees is less pronounced than that of the B.S. degrees (see Fig. 2).

Figure 3 shows that the number of degrees in aerospace engineering continues to be less than 8 percent of the total engineering degrees. These ratios peaked in 1969 for the B.S. degrees (6.57 percent); in 1950 for the M.S. degrees (7.67 percent) and in 1954 for the Ph.D. degree (7.29 percent).

3. A LOOK AT THE FUTURE

In order to assess the adequacy of aeronautics and aerospace engineering curricula it is necessary to identify: a) technical needs for new and projected aeronautical and space systems; and b) the likely characteristics of the future aerospace engineering work environment. Then an examination must be made of how well current curricula help in meeting these needs and in preparing the students for the future work environment.

3.1 New and Projected Aeronautical and Space Systems

Some of the future systems are listed in Tables 1 and 2 and are shown in Figs. 4 through 36. The information about these systems are contained in reports by the Aeronautics and Space Engineering Board of the National Academy of Engineering (Refs. 11 and 12); the Office of Science and Technology Policy (Ref. 13); the NASA Advisory Council (Ref. 14); NASA's Long-Range Program and Space Systems Technology model (Refs. 15 and 16); and the report of the National Commission on Space (Ref. 1). Photographs and artists' drawings included in this report were obtained from NASA Centers and from various aircraft and aerospace companies.

The three national aeronautical research and development goals identified by OSTP and NASA are:

1) to advance the technology for a new generation of fuel-efficient subsonic aircraft and advanced rotorcrafts

2) to develop pacing technologies for efficient long-distance supersonic cruise, and

3) to secure future options by pursuing research towards the capability for transatmospheric flight

The future aeronautical systems include: rotorcraft, subsonic, supersonic, and extremely high-altitude aircraft, and transatmospheric vehicles (including the National Aerospace Plane).

The goals of the national strategy for the civil space program include:

1) insure routine, cost-effective access to space with the space transportation system

2) establish a permanently manned presence in space to explore, prospect and settle the solar system

3) encourage commercial expendable launch vehicle activities

4) stimulate private sector commercial space activities

The three major space transport needs are: cargo transport to low-earth orbit; passenger transport to and from low-earth orbit; and round-trip transfer beyond low-earth orbit.

The driver missions for the space technology focus, as defined by NASA's Office of Aeronautics and Space Technology (OAST), are given in Fig. 19. The new and projected space systems include the space station and extensions such as orbital factory, the space transportation systems (earth to orbit vehicles, orbit maneuvering and orbit transfer vehicles), spacecrafts used for manned and unmanned observation of near earth environment, astronomy missions, exploration of the planets of the solar system, exploration of comets and asteroids, and permanent lunar and martian bases.

Some of the aforementioned systems have already passed the conceptual stage and are in the testing stage; others have just been conceptualized.

3.2 Technical Needs in the Materials and Structures Areas

Advances in structures, materials and manufacturing technologies will play a dominant role in the design and development of future aeronautical and space systems. In addition, the realization of these systems requires technology advances in a number of other disciplines including propulsion, aerodynamics, controls, avionics, optics and acoustics. Some of these technology needs are outlined in Refs. 11, 12 and 17 for the future aeronautical systems, and in Refs. 1, 15, 16 and 18 for the space systems. Among the technical needs for the future systems are:

1. High-performance materials, novel processing methods, and advanced structural concepts to achieve significant weight reductions, improved performance, higher-operating temperatures, longer lives, and/or lower costs. The high performance materials include new aluminum-lithium alloys, rapid-solidification-rate (RSR) metals, high-temperature ceramic composites, carbon-carbon composites, thermoplastics and advanced metal-matrix composites. The processing methods include rapid solidification, powder metallurgy, sol-gel techniques, and chemical vapor deposition. Novel processing methods also include superplastic forming and diffusion-bonding concepts, and advanced joining concepts such as adhesive bonding. The structural concepts include structural tailoring of composites to achieve high levels of performance which cannot be achieved by traditional materials.

   The new aluminum-lithium alloys offer weight reduction and stiffness improvements. Rapid-solidification-rate metals and carbon-carbon composites have the potential of operating at very high temperatures while retaining the properties of usability and long life. Superplastic forming and diffusion-bonded titanium sandwich construction is promising for laminar flow control. Advanced joining concepts have the potential of reducing manufacturing costs as well as allowing novel geometrically efficient concepts.

2. Adaptive structures in which the vehicle configuration automatically adapts or can be controlled to adapt its shape to obtain optimum performance throughout the flight envelope.

3. Very high precision shaped and controlled space structures subjected to dynamic and thermal loads.

4. Efficient structural systems for spacecrafts subjected to very high accelerations.

5. Improved orbital delivery systems, emphasizing larger payloads, lower cost, and high reliability.

6. Innovative techniques for packaging, deploying, assembling, and fabricating very large space structures, including the use of robotics. Of particular importance are the methods of joining members of flexible structures and techniques for artificially stiffening these structures.

7. Increasingly higher level of integration of technical disciplines is required to achieve significant improvement in vehicle performance, safety and economy. Examples are provided by the structures/thermal/propulsion/controls integration of supersonic and hypersonic aircraft and the structures/thermal/controls/optics integration for large flexible space vehicles.

8. Development and use of electromagnetic and optical sensors for onboard fault-testing of unconventional and hard-to-inspect structural components.

9. Improved design of structural details such as joints, damping, vibration isolation and suppression mechanisms.

10. Improved life prediction methods for structural components subjected to very high temperatures.

3.3 Future Aerospace Engineering Environment

The work environment of the aerospace engineer is likely to have a number of major changes from the present environment including:

a) Aerospace engineers will be used less and less for formatted tasks. Many of these tasks may be carried out by advanced analysis and design systems incorporating knowledge-based expert systems.

b) The brain centers of the engineering organization will include single user workstations with high performance processors, a bit-mapped high resolution display, over a megabyte of storage and high capacity secondary storage.

c) Extensive use will be made of robotics, sensor-intensive adaptive machines for flexible manufacturing, and CAD/CAM. This will result in a high degree of automation of the processing, assembly and inspection of components and structures, as well as in precision control of dimensional and geometrical tolerances.

d) Advances in the communications and networking technology will provide aerospace design engineers with the facility of on-line contact with manufacturing, test, and quality control.

4. CURRENT STATUS OF FLIGHT-VEHICLE STRUCTURES EDUCATION

This section gives the technical contents of the flight-vehicle structures programs at 41 U.S. universities. The information presented herein is based on a questionnaire sent to all U.S. institutions with accredited aeronautics/aerospace engineering programs. The number of these institutions is 67. Only 63 of these programs offer flight structures courses at the undergraduate and/or graduate level, and of those, 41 institutions responded to the questionnaire.

4.1 Analysis of Flight-Vehicle Structures Curricula

For easy reference and comparison, the information is arranged in tabular form (Table 3). The institutions are listed alphabetically according to the name of the state. For convenience, the tables are divided into four sections are follows:

Section I gives general information about the aerospace programs at the different institutions, including degrees awarded, total number of credit hours required for each degree, number of faculty members involved in teaching the flight-vehicle structures courses, and the number of degrees awarded during 1983-1986.

Sections II and III list the number of credit hours and courses (required and electives) dealing with flight-vehicle structures in both the undergraduate and graduate programs. The courses are divided into nine groups as follows:

1. Mechanics of deformable solids

2. Structural analysis and structural stability

3. Structural dynamics

4. Experimental stress analysis

5. Materials for flight structures and methods of construction

6. Aeroelasticity and Aeroinelasticity

7. Structural design

8. Computational mechanics and CAD/CAM

9. Multidisciplinary design (integration of structures with other disciplines)

Section IV lists the educational aids used in flight-structures education including experimental facilities, computer-aided instruction, computer graphics and video courses, as well as industry programs.

Figures 37 to 40 show the total number of credit hours required for the B.S. degree, the number of required credit hours in each of the first eight groups of Section II, as well as the total number of credit hours in these groups, and the ratio of these totals to the required credit hours for the B.S. degree. For the sake of comparison, the number of quarter hours are converted to "equivalent" semester hours through multiplying by 2/3. Also, for easy reference, different designations (shadings) are used in Figs. 37 to 40 for universities with semester, quarter and trimester systems.

An examination of Table 3 and Figures 37 to 40 reveals:

1. The number of credit hours required for the B.S. degree ranges between 121 hours (M.I.T.) and 192 hours (Air Force Institute of Technology). The average for the 36 schools with B.S. degrees is 136 hours. Because of the required military subjects, the three military schools (U.S. Air Force Academy, U.S. Naval Academy, and Air Force Institute of Technology) have higher number of required credit hours for the B.S. degree.

2. The total number of credit hours in the first eight groups of Section II ranges between 9 (University of Colorado) and 45.50 (Boston University) with an average of 22.21. This average is about 16 percent of the total credit hours. The high number of credit hours for Boston University reflects an emphasis on computational mechanics and CAD/CAM in their undergraduate curriculum.

3. The least-emphasized areas among the first eight groups of Section II are aeroelasticity, and materials and methods of construction. Only three schools required undergraduate aeroelasticity courses, and the average number of required credit hours in the materials area is less than 1.5. The two most emphasized areas are structural

analysis (with an average of 5.54 credit hours), and computational mechanics and CAD/CAM (an average of 4.5 credit hours). However, a wide variation exists between different schools in these two areas. The number of credit hours in the structural analysis area ranges between 2.0 (State University of New York at Buffalo) and 13.0 (University of Kansas). In the computational mechanics and CAD/CAM area the range is between 0 and 18 (Boston University).

4. Of the 41 schools included in the survey, eight use computer-aided instruction, 15 use video courses, and 18 use graphics to enhance the presentation of physical concepts. Fourteen schools have no facilities for experimental stress analysis and 11 schools have no interaction with industry.

5. A large percentage of the flight-vehicle structures courses are taught by other departments. This is particularly true of the graduate courses.

4.2 Areas of Concern in Flight-Vehicle Structures Education

Although considerable change in the contents of the flight-vehicle structures curricula took place in the 1960's, only little change has been made since then. An examination of the current flight-vehicle structures curricula at different U.S. institutions in light of the technical needs for new and projected aeronautical and space systems reveals a number of deficiencies and areas of concern. In general, most of the current flight-vehicle structures curricula do not reflect the advances in engineering practice and are not adequate to meet the challenges of the 1990's and beyond. This is particularly true in the areas of materials, manufacturing technology, design system studies and space applications. Specifically, the following observations can be made:

1. Not enough emphasis is placed on the integration of the structures discipline with other disciplines such as controls, propulsion and optics.

2. Most curricula include design courses. However, they generally do not include the systematic approach for synthesizing several designs and analyzing the proposed alternatives to determine which is most nearly optimum under a given set of constraints. Evaluation of alternatives involves manufacturing techniques and cost.

3. The analysis and design of spacecraft are now mature endeavors, and the design of the space station is fast approaching the same degree of maturity. This is not reflected in most of the aerospace curricula. Almost none of the undergraduate curricula, and only few of the graduate curricula, include analysis of large flexible structures (with control interactions), new materials for space and entry applications (e.g., metal matrix and carbon-carbon composites), special mechanisms for solar panels, and zero gravity dynamic simulations.

Other areas of concern, which are not limited to flight-vehicle structures but apply to other engineering disciplines, include: faculty shortages, crowded, poorly-equipped laboratories, and aging and outmoded research equipment and facilities. These areas of concern have been identified by professional engineering societies, e.g., American Institute of Aeronautics and Astronautics (AIAA), American Society of Engineering Education (ASEE), and industry groups. A recent study by the American Society of Engineering Education entitled, "Quality of Engineering Education Project (QEEP)," see Refs. 9 and 10, addresses these areas of concern and give recommendations for engineering faculty development. A recent report by an ad hoc action planning

committee proposed that the Academic Affairs Committee of AIAA develop a model aerospace engineering curriculum to serve as a basis for curriculum evaluation.

In recognition of the need for more space-related courses at universities, a proposal was recently made for a degree program in Astronautical Engineering that specializes in spacecraft systems (Ref. 19). The core courses in the proposed program include: Introduction to space systems, orbital mechanics and mission design, structural design and analysis, spacecraft power, propulsion, spacecraft dynamics and control, spacecraft instrumentation and payloads, telecommunication and data handling, thermal environmental control, space system laboratory, and spacecraft system design.

A set of elective courses were also proposed which include: Astronomy and space science, physical optics and optical analysis, space mission planning and design, human factors/manned space flight, principles and techniques of remote sensing, systems engineering, manufacturing for space, launch vehicle design, inertial navigation, dynamic and thermodynamics of planetary entry, laser design and applications, and artificial intelligence.

Only two degree programs in Astronautical Engineering currently exist in the U.S. The first is a B.S. program at the Air Force Academy and the other is an M.S. program at the Air Force Institute of Technology.

5. GOALS AND KEY ELEMENTS OF AEROSPACE ENGINEERING EDUCATION

In order to meet the challenges of the projected aeronautical and space systems for the year 2000 and beyond, there is a need for a thorough re-evaluation of aerospace engineering education, including the flight-vehicle structures curriculum which has changed incrementally over the past two decades. In addition to the examination of the course contents, the goal of aerospace engineering education and the key elements of this education, namely the faculty, the delivery system and the computer, need to be examined in the light of future aerospace engineering environment.

5.1 Goal of Aerospace Engineering Programs

A quality aerospace (or any other) engineering program is one that generates innovative people with knowledge, skill and vision. In such a program students learn the "engineering approach" to problem solving. This includes:

a) knowing how to define the engineering problem, identify its components and approach a solution systematically

b) knowing the trade-offs between what is theoretically possible and economically feasible

c) using the classrooms and the laboratories to develop and nurture the innovative capability of the students

d) training the student to adapt to the fast-paced aerospace engineering environment through commitment to lifelong learning

The first two items lead to the two conflicting requirements of:

1) thorough grounding in both the fundamental engineering principles and the development of analysis tools, and

2) high degree of specialized technical knowledge

The result is having to learn more and to learn it faster. Hence, an examination of the effectiveness of the delivery system seems to be in order.

5.2 Delivery System

Teaching has changed little over this century. It still relies heavily on the lecture recitation format. All students are expected to absorb the same material in the same time irrespective of their abilities, habits, speed of perception and well being. Advances in instructional technology (e.g., videotape courses, computer-based courses, instructional TV and movies) have not been sufficiently used in improving the teaching/learning process. Some of these advances are described in this subsection.

1) Instructional TV. The use of **instructional TV** dates back to the 1950's. It started in the form of **passive television viewing.** Courses were taped in a university studio and shipped to students on a flexible viewing schedule. As TV became portable, instructional TV moved to the classroom.

To improve the effectiveness of instructional TV, a hybrid combination of videotape and a local instructor were used **(tutored video instruction).** In 1976 the Association for Media-Based Continuing Education for Engineers (AMCEE), a consortium of 33 universities, was formed. Four hundred and eighty three videotape courses in 16 disciplines have been developed by AMCEE. The list of videotape courses which are useful for flight-vehicle structures education in instructional TV are given in Table 4.

Two important developments in instructional TV are worth noting. The first is **ITFS** (instructional TV-fixed system) with **audio link** (a talk back capability through telephones) with the originating classroom.

The second is **instructional TV** via **satellite.** In 1984 the National Technological University (NTU) was formed to transmit graduate courses via networks to engineers at college campuses and industrial firms in 48 states.

2) Computer-Based Instruction (CBI). Computer-based instruction includes a broad range of applications that can be divided into the two general categories of **computer-assisted instruction** (CAI) and **computer managed instruction** (CMI). The first category includes such activities as drill-and-practice, tutoring, simulations, information retrieval, and problem solving. The second category includes instructional support functions such as testing, prescribing, recordkeeping, monitoring, and time and resource management.

Computer-assisted courses have been used at few universities since the 1960's. These courses have generally been based on computer systems such as PLATO (Programmed Learning for Automated Teaching Operations) developed at the University of Illinois and marketed by Control Data Corporation.

Of the 41 Aerospace and Aeronautics departments included in the present study, 18 use computer graphics to enhance the presentation of physical concepts, and only 8 make use of computer-aided instruction. The limited use of computer technology in education may be attributed to:

a) The early educational, and most of the presently available commercial software, does not actively engage the user in an intellectually-challenging task. Courseware was primarily aimed at training or remediation rather than acquisition of new understanding, and

b) Relatively high cost of delivery system. As an example, the PLATO system until recently required a sophisticated mainframe in order to run the software.

The wide availability and increasing speed and capacity of new and projected microcomputers/workstations have prompted a number of universities (notably Brown, Carnegie-Mellon and MIT) to examine the potential of advanced workstations for delivering educational services. An inter-university consortium for educational computing (ICEC) was established in 1983, with 16 universities and colleges participating. The principal goal of the consortium is to develop high-quality educational uses of the powerful workstations. It is expected that in the late 1980's advanced workstations with 64-bit architecture, megabytes of Random Access Memory (RAM), megabytes of storage, millions of instructions per second (MIPS), high resolution megapixel displays, and megabit transmission rates within local area networks (5M machines) will be widely available and inexpensive. These workstations can be linked together in local area networks (LAN) using fiber optics links to distribute information to offices, classrooms and even to student living quarters.

Educational courseware is currently being developed by publishers, universities and computer vendors (e.g., McGraw-Hill/Carnegie-Mellon University joint project, Control Data Corporation, and Digital Courseware). The two basic approaches for creating courseware are:

a) **Authoring system method** based on using a collection of utilities that create a series of frames. Each frame permits some combination of textual display, input parsing and branching (e.g., IBM PRIVATE TUTOR and the AUTHOR from Phoenix Performance Systems, Inc.). This method may have built-in capabilities for sophisticated graphics and/or calculations. It is particularly useful for the nonprogrammer but it is slower and requires more memory; and

b) **Programming languages** which permit more flexibility in the design and implementation of the instructional program (e.g., CDC TUTOR). There is a great need for an integrated authoring environment that simplifies the task of developing courseware for augmenting the classroom instruction.

Proper use of new instructional technology, in particular, the combination of computing and communication technologies, is likely to produce major changes in the way engineering education is organized and delivered, and to improve substantially the efficiency and effectiveness of the faculty. This will be discussed in succeeding subsections.

5.3 Role of Faculty

The human instructor is a key element in the learning environment. His role should be to guide, challenge, motivate, counsel and encourage the student; i.e., the faculty's role is to serve as a resource, a beacon, a role model, and an evaluator. In order to increase the effectiveness of the faculty some of the mundane tasks carried out by the faculty have to be relegated to the computer. Also, the concept of an instructional team first proposed by N. Suh (Ref. 20) and described in the subsequent section should be vigorously pursued.

5.4 Role of Computers

A recent report by the American Society of Engineering Education Committee on Educational Technology has identified a number of major applications of the computer in the educational process (Ref. 21). In terms of flight-vehicle structures, and aerospace engineering in general, some of the applications of microcomputers/workstations are:

1. **Simulator of the response of complex structural systems.** While all students should understand the basic structural principles, not all can apply these principles to flight vehicles of meaningful size. The availability of commercial finite element programs for microcomputers (e.g., ANSYS, GIFTS, MSC/Pal) will allow students to solve real (though scaled down) flight vehicle problems.

2. **Virtual experimental facility.** In the absence of adequate test facilities, the computer, with the aid of appropriately constructed software, can be used to simulate structural, dynamic and wind tunnel experiments. Moreover, since physical insight is rarely derived from a single experiment, the computer provides the student with the facility to study the effects of changing the design variables of the flight vehicle on their response and failure characteristics. However, since observations of real tests and experiments are invaluable, the experiments can be conducted in industry (or government laboratories), and transmitted to the classroom via satellite.

3. **Expert tutor.** With the use of AI-based expert systems, the computer can design problems in structural analysis, monitor a student's effort to solve them, diagnose the student's misconceptions in the formulation of the problem (e.g., through examination of equilibrium and compatibility equations) and devise strategies to remedy them. It can advise the student, upon request, in selecting appropriate optimization algorithms for a design problem.

The creation of software for an expert tutor requires much more sophistication than the early computer-aided instruction software. The software needs to work with the mathematical symbols used in representing the structure, loadings, and constraints, and to manipulate mathematical expressions involving these symbols. Also, a general inference capability for the class of problems under study must be developed and a careful study of common errors made by students has to be undertaken. An expert tutoring system for enhancing the learning of basic undergraduate electrical networks course is currently being developed at Carnegie-Mellon University.

4. **Electronic textbook.** The computer can enhance the physical understanding a great deal with its abilities to: a) manipulate and edit pictures; b) graphical representation of complex functions; and c) presenting symmetry concepts. Moreover, its facility for animation can prove invaluable for time-dependent phenomena.

5. **Electronic blackboard.** Many complex systems and phenomena are difficult to draw on the blackboard, and once they are drawn, are difficult to change. Computer-generated graphics used in the classroom can be displayed on high-resolution large screens. Some universities (e.g., Brown University) have already developed classrooms designed for computer-based demonstrations. The software used in generating the graphical representations of these phenomena can also be made available to students for further study outside the classroom.

6. RECOMMENDATIONS FOR INCREASING THE EFFECTIVENESS OF FLIGHT-VEHICLE STRUCTURES EDUCATION

In this section a number of recommendations are made for increasing the effectiveness of flight-vehicle structures education. These recommendations are based on the present study as well as on the author's contacts with several institutions. Some of the recommendations are particular to flight vehicle structures; others are general and apply to other disciplines as well. The recommendations are:

1. **Course contents.** There is a definite need to bring the advances in structures technology and new methodology for solving structures problems into both the undergraduate and graduate curricula. This is particularly true for space systems and may, in some cases, result in increasing the course content and poses the challenge of how to accomplish this without sacrificing the quality or the level of comprehension. The challenge can be met by:

a) close coordination between different courses - emphasizing the coupling with no duplication

b) new instructional technology as described in the next subsection

c) emphasizing cross-disciplinary and multidisciplinary aspects of aeronautical and aerospace systems at the senior undergraduate and graduate levels through:

i) forming new combinations of existing courses and developing new courses. As an example of this, combining aeroelasticity and active controls courses into a course on servo-aeroelasticity

ii) organizing directed studies for students on multidisciplinary projects (treated as elective courses)

iii) providing the students with "hands-on" experience with real (although scaled-down) flight vehicles

2. **New instructional technology.** In addition to using the advanced microcomputer/workstation in the manner described in the preceding section, the learning process can be enhanced by combining the microcomputer courseware and videodisk to augment the classroom instruction. This active learning system combines the advantages of the video with the storage, speed and branching logic of the microcomputer to provide the interaction within the system and can be used as follows:

a) a narrator first reviews (or discusses in detail) the basic concepts presented in the lecture

b) an on-disk program illustrates the concepts

c) the narrator then reiterates the salient points and poses a number of questions

d) an AI-based expert system is used to evaluate the level of understanding of the user and review the material as needed

The technology for this adaptive learning system is currently available. It requires microcomputer/workstations; a laser video disk unit; a computer/laserdisk interface; and a set of earphones. The key element of the system is the interface card, which toggles the video monitor between standard television and RGB signals. It is connected to the videodisk unit through either the serial or parallel ports and allows the software to direct exactly which video and/or audio sequences will be shown on the screen.

3. **Formation of instructional team for design courses.** This concept was suggested by N. Suh of NSF. It is particularly useful for senior and graduate level design courses. One professor on campus collaborates with two or more instructors from industry in teaching a course. The professor presents the basic principles on campus, then the industry team teaches applications from their industrial site. The lectures are televised in the campus classroom. A television monitor or telephone is provided in the industrial firm for two-way, live interaction between students and lecturer.

Although close coordination between the members of the team is required to realize the full potential of this concept, several benefits can be gained by universities, students, faculty and industry including:

a) more than one aerospace department can participate in the program

b) students learn to systematically apply the basic principles to synthesize real (though, possibly scaled-down) flight vehicles. This includes also system integration and testing (using up-to-date equipment at industry).

c) since first-rate experienced engineers from industry can be included in the team, regardless of their location students will be exposed to the best minds

d) university faculty can benefit from the industrial experience

e) engineers in industry can benefit from the teaching experience, acquire more current information and interact with prospective employees

f) industrial firms benefit from enhanced engineering education which produces aerospace engineering graduates with the necessary background

4. **Development of courseware for flight vehicle structures.** This can be a joint venture between universities and computer vendors, with partial government support to cover the initial cost for refining and testing the methodology used in the courseware.

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APPENDIX I - CURRENT GOVERNMENT SUPPORTED PROGRAMS

The following government supported programs are likely to have an impact on aerospace engineering education as well as engineering education in general.

1. NASA/University Advanced Design Program. Twenty-nine universities are currently participating in this program which is funded by NASA. Each participating university works with one of the NASA centers. NASA provides the participating universities with reference material, reports, videotapes and special lecturers from NASA and industry. During the summer selected students work at their assigned NASA Center. The subjects selected are advanced aeronautical and space design concepts, and are listed in Table 5 along with the name of the University and the NASA Center.

2. Centers of Excellence. The Army Research Office has established in 1983 three centers for vertical flight technology (rotary wing aircraft). The objectives of these centers are: a) provide advanced training and education in rotary wing technology; and b) serve as focal points for conducting state-of-the-art research on rotorcraft. The centers are located at Georgia Institute of Technology, Rensselaer Polytechnic Institute and the University of Maryland.

3. University Research Initiative (URI) Program. The Department of Defense, through the Departments of the Army, Navy, Air Force, and the Defense Advanced Research Projects Agency, initiated this program in 1986 to strengthen the capabilities of the universities to perform research and to educate scientific and engineering personnel in key disciplines which are important to meet the national defense needs. The ten technology areas identified are:

- o analysis, modeling and simulation
- o technologies for automation (robotics, artificial intelligence, computers, manufacturing science and controls)
- o submicron structures
- o biotechnology
- o electro-optic systems and signal analysis
- o high performance materials (including lightweight flexible structures)
- o fluid dynamic systems
- o human performance factors
- o environmental science and technology
- o propulsion technology

In the first year of this multiyear program seventy institutions are funded to work on 86 research programs. The funding covers graduate fellowships or grants, research instrumentation, and exchange of scientists and engineers with other research organizations, particularly DoD laboratories.

4. Engineering Research Centers. The National Science Foundation established six centers in 1985 and five more centers in 1986. The objective of these centers is to provide a cross-disciplinary approach in the conduct of engineering research. A detailed discussion of the objectives and expectations from the centers is given in Ref. 22. The six centers established in 1985 are:

a) Robotics Systems in Microelectronics - University of California at Santa Barbara

b) Telecommunications - Columbia University

c) Composites Manufacturing - University of Delaware in collaboration with Rutgers University

d) Systems Research - University of Maryland in collaboration with Harvard University

e) Biotechnology Process Engineering - Massachusetts Institute of Technology

f) Intelligent Manufacturing Systems - Purdue University

The five centers established in 1986 are:

a) Engineering Design - Carnegie-Mellon University

b) Advanced Combustion - Brigham Young University

c) Advanced Technology for Large Structural Systems - Lehigh University

d) Net Shape Manufacturing - Ohio State University

e) Compound Semiconductor in Microelectronics - University of Illinois at Urbana-Champaign

5. University Centers for the Commercial Development of Space. The centers for the commercial development of space have been established by NASA to stimulate high technology research, development and production in the space environment. The nine centers established to date, their technology focus and affiliates are listed in Table 5.

6. NASA Graduate Student Researchers Program (GSRP). This program supports eighty new graduate students annually. Forty of these students are supported by the Office of Space Science and Applications at NASA Headquarters, and the other forty by eight NASA field centers.

7. DoD University Instrumentation Program. This is a five year, $150 million initiative to upgrade university research instrumentation, funded at $30 million per year through fiscal 1987.

8. National Technological University (NTU). This is a consortium of 24 major engineering schools whose faculty deliver advanced degree courses via satellite to engineers employed in commercial and DOD laboratories and installations. Financial support is provided by DoD and industry (GTE, Hewlett-Packard,IBM, and other major employers of engineers).

TABLE 1 - LIST OF FUTURE AERONAUTICAL SYSTEMS AND SOME OF THE ASSOCIATED TECHNICAL NEEDS IN THE STRUCTURES AND MATERIALS AREAS

Class	Goals	Candidate Configurations and Vehicles	Some of the Technical Needs
Rotorcraft Figs. 4-6	To build rotorcraft with increased speed; greater lift; longer range; improved reliability and safety; reduced noise and vibration	a) Next-Generation Helicopters o Single rotor o Tandem rotor o Advancing blade concept o Conventional compound b) Advanced High Speed Rotorcraft o Tilt rotor o Folding tilt rotors o Stopped rotor (X-wing) o Single stowed rotor c) Large-Passenger/Cargo Helicopters	o New rotor concepts and advanced transmissions o Advanced composite materials and manufacturing techniques o Nondestructive testing and evaluation o Design/analysis capability for low vibrations and low noise
Subsonic Aircraft Figs. 7-9	To build fuel-efficient, affordable aircraft operating in a modernized national airspace system	o Commercial transport o Short/medium range (propfan) o Long range (turbofan or propfan) o Commuter aircraft o Military transport o Short haul o Long haul o Assault o Subsonic strike aircraft	o Advanced material and structural concepts o Plastic and metal matrix composites o Aluminum-lithium alloys o Superplastic forming o Diffusion-bonded Titanium o Sandwich Construction o Advanced joining concepts and adhesive bonding o Sensors for on-board fault testing for unconventional and hard to inspect structures
Supersonic Aircraft Figs. 10-14	To attain long distance efficiency	o Commercial supersonic transport o Advanced fighter o Supersonic short takeoff-vertical landing aircraft (STOVL)	o Metal-matrix composites o Rapid solidification materials and ceramics o Advanced structures for propulsion system including airframe/propulsion integration
Hypersonic Aircraft and Missiles Fig. 15	To develop manned and unmanned hypersonic vehicles to operate in the sensible atmosphere at Mach 5-12. These include long-range civilian transports.	o Commercial hypersonic transport o Military penetrator aircraft concept o Military hypersonic accelerator vehicle o Hypersonic airbreathing missile	o Metal-matrix composites o Airframe/propulsion integration o Advanced programmable controls o Convectively cooled structural concepts o Cryogenic tanks
Extremely High-Altitude Aircraft Figs. 16-17	To conduct long-endurance missions at high altitudes (60,000-100,000 + feet) at speeds 300 knots or less. Missions include communications relay; earth-resource monitoring; atmospheric sampling; and surveillance.	o Solar-powered aircraft o Microwave-powered aircraft o Combustible fuel aircraft o Blimp	o Ultra-lightweight structures o Long-endurance and lightweight propulsive and energy storage systems

TABLE 1 (CONCLUDED)

Class	Goals	Candidate Configurations and Vehicles	Some of the Technical Needs
Transatmos-pheric Vehicles Fig. 18	To provide a capability for routine cruising and manuever into and out of atmosphere with takeoff and landing from conventional runways	o National Aerospace Plane (NASP) or X-30 Program (Single-stage-to-orbit vehicles) o Multistage vehicles (with rocket propulsion)	o Lightweight and high strength thermostructural design concepts o Durable, reusable thermal protection system o Advanced composite materials o Highly integrated airframe/ propulsion system (blended engine/ airframe)

TABLE 2 - LIST OF SOME OF THE MAJOR FUTURE SPACE SYSTEMS

Category	Vehicles
Space Transportation Systems Figs. 20-24	Launch Vehicles o Orbit-on-demand vehicle for deployment, space station visit, repair/service, retrieve/rescue, and observation o Heavy lift launch vehicle o Shuttle II Service Vehicles o Orbital Maneuvering Vehicle (OMV). For local transportation between space station and its outlying cooperating elements Reusable, Two-Way Long-Range Space Transportation Systems o Orbital transfer vehicle (OTV) for transportation between LEO and GEO o Translunar orbital transfer vehicle for transportation to lunar base o Assemblies of OTV for launching payloads into trajectories for solar system exploration and manned mission to planets
Spacecrafts for Astronomy Missions and Observation of Near-Earth Environment Figs. 25-28	o Hubble Space Telescope (HST) o Gamma Ray Observatory (GRO) (1987) o Cosmic Background Explorer (COBE) (1988) o Extreme Ultraviolet Explorer (EUVE) (1989) o X-Ray Timing Explorer (1990) o Tithered Satellite System o Upper Atmosphere Research Satellite
Spacecrafts for Planetary and Solar Exploration Figs. 29-33	a) Core Program recommended by Solar System Exploration Committee (SSEC) Probes for Inner Planets (Near Universe) o Venus Radar Mapper (1988) o Mars Geoscience Climatology Orbiter (1990) o Titan (Satellite of Mars) Probe (mid to late 1990's) Probes for Outer Planets o Galileo Jupiter Orbiter and Probe (1986) Probes for Small Bodies (Comets and Asteroids) o Comet Rendevous/Asteroid Flyby Mission (1990) b) Spacecrafts for other missions: o Starprobe o Mars aeronomy orbiter o Mars surface probe o Mars rover and sample return

TABLE 2 (CONCLUDED)

Category	Vehicles
Spacecrafts for Planetary and Solar Exploration Figs. 29-33 (Cont'd.)	o Venus atmospheric probe o Lunar geoscience orbiter o Saturn orbiter o Saturn probe o Uranus probe o High-speed comet sample return o Multiple mainbelt asteroid orbiter and flyby
Large Space Systems and Planetary Bases Figs. 34-36	o Mobile communication satellites o Large deployable reflectors o Space station in low earth orbit (LEO) o Large unmanned platforms housing instruments and experiments in LEO o Large commercial facility (orbital factory) in LEO o Geosynchronous platform o Lunar base o Mars base

Notes: 1) Low Earth Orbits (LEO) are those just beyond the Earth's atmosphere.
2) Geostationary (geosynchronous) orbit - 22,300 miles above Earth's equators is the orbit in which spacecraft match Earth's 24-hour rotation and hold fixed longitudes.

TABLE 3 - DETAILED INFORMATION ON FLIGHT STRUCTURES CURRICULA

PART I - GENERAL INFORMATION

		Auburn University	Univ. of Arizona	California Institute of Technology	CA Poly. St. Univ. at San Luis Obispo	San Diego State Univ.	Stanford University	Univ. of California at Davis	Univ. of South. CA	U.S. Air Force Academy	Univ. of Colorado at Boulder	GWU (JIAFS)	Embry-Riddle Aeron. Univ.	Univ. of Florida at Gainesville	Georgia Institute of Technology	Univ. of Illinois at Urbana-Champ.	Purdue University	Tri-State University	Univ. of Notre Dame	Univ. of Kansas	Wichita State Univ.
1.	Degrees in Aeronautics and Aerospace Awarded by the University																				
	B.S.	•	•		•	•		•	•	•	•		•	•	•	•	•	•	•	•	•
	M.S.	•	•	•	•	•	•		•		•	•		•	•	•	•		•	•	•
	Engineer (or Professional)			•			•		•			•		•						•	
	Ph.D. or D.Sc.	•	•	•			•		•		•	•		•	•	•	•		•	•	•
2.	Academic Year Divided into Quarters (Q), Semesters (S) or Trimesters (T)	Q	S	Q	Q	S	Q	Q	S	S	S	S	T	S	Q	S	S	Q	S	S	S
3.	Total Number of Credit Hours Required for B.S. Degree	208	130		206	133		192	129	147	128		136	135	206	134	131	206	134	137	133
4.	Total Number of Semester (or Quarter) Course Credit Hours Required for:																				
	M.S. Degree (Nonthesis Option)			45		30	45		27		30	33		32	50		30		30	33	32
	M.S. Degree (Thesis Option)	45	48		45	24-27			27		24	24		30	33	24	21		24	30	26
	Engineer (or Professional)						15		57					30*						36/72	
	Ph.D. or D.Sc. Degree (Total Credit Hours Past the M.S. Degree Including Thesis)	40-75	56	45			45		30		30	30		90**	25	48	36		24	60	60
5.	Number of Faculty Members Involved in Teaching the Flight Structures Courses (Parts II and III)																				
	Full-Time Regular Faculty	2	3	3	2	3	6	1	1/2	4	1	1	4	3	9	4	6	1	2.5	1	3
	Part-Time Faculty	1	0	0	1	3		2	0					1	2	0				0	0
	Instructors		0	0				0	1					0	0	5				0	0

*Past M.S. degree
**Past B.S. degree

TABLE 3 (CONTINUED)

PART I - GENERAL INFORMATION

		Univ. of Maryland	U.S. Naval Academy	Boston University	Massachusetts Institute of Technology	Univ. of Michigan	Mississippi State Univ.	Parks College of St. Louis University	Univ. of Missouri	Rutgers University	Cornell University	New York Institute of Technology	Rensselaer Polytechnic Institute	State Univ. of New York at Buffalo	Air Force Institute of Technology	Ohio State University	Univ. of Cincinnati	Univ. of Oklahoma	Texas A&M University	Univ. of Texas at Austin	Univ. of Virginia	Virginia Poly. Inst. and St. Univ.
1.	Degrees in Aeronautics and Aerospace Awarded by the University																					
	B.S.	•	•	•	•	•	•	•	•			•	•	•	•	•	•	•	•	•	•	•
	M.S.	•		•	•	•	•		•	•	•		•	•	•	•	•	•	•	•	•	•
	Engineer (or Professional)				•	•					•				•			•	•			
	Ph.D. or D.Sc.	•			•	•	•		•	•	•		•			•	•	•	•	•	•	•
2.	Academic Year Divided into Quarters (Q), Semesters (S) or Trimesters (T)	S	S	S	S	T	S	T	S	S	S	S	S	S	Q	Q	Q	S	S	S	S	Q
3.	Total Number of Credit Hours Required for B.S. Degree	133	149	132	121	128	139	146	132			139	134	136-138	192	210	203	133	138	132	132	204
4.	Total Number of Semester (or Quarter) Course Credit Hours Required for:																					
	M.S. Degree (Nonthesis Option)	30		32		30				30	30		6	32		45	51		36	36	30	45
	M.S. Degree (Thesis Option)	24		28	22-½	24	24		24	24			6	32	48	50	46	30	32	30	24	30
	Engineer (or Professional)				54	30												60	36			
	Ph.D. or D.Sc. Degree (Total Credit Hours Past the M.S. Degree Including Thesis)	54		32	14	30	50			42			18	32	48	65	90**	60	64		24	90
5.	Number of Faculty Members Involved in Teaching the Flight Structures Courses (Parts II and III)																					
	Full-Time Regular Faculty	3	2	3	7	4	1	3	4	1	2	1	4	1	5	2	5	3	4	6	2	5
	Part-Time Faculty	2-3	1	1		0		0	3	1	0	1	1		1		1	0	0		0	1
	Instructors			1		1/4*		0			0					1		0	1		0	

*Visiting Professor
**Past B.S. degree

TABLE 3 (CONTINUED)

PART I - GENERAL INFORMATION

6. Number of Degrees of Aeronautics and Aerospace Awarded in the Last Four Calendar Years		Auburn University	Univ. of Arizona	California Institute of Technology	CA Poly. St. Univ. at San Luis Obispo	San Diego State Univ.	Stanford University	Univ. of California at Davis	Univ. of Southern CA	U.S. Air Force Academy	Univ. of Colorado at Boulder	GWU (JIAFS)	Embry-Riddle Aeron. Univ.	Univ. of Florida at Gainesville	Georgia Institute of Technology	Univ. of Illinois at Urbana-Champ.	Purdue University	Tri-State University	Univ. of Notre Dame	Univ. of Kansas	Wichita State Univ.
1983	B.S.	36	31		55	27		22	51	57	45	0	98	37	75	78	98	15	39	19	17
	M.S.	3	4	18	0	3	48		14		9	11		7	10	6	18		7	4	5
	Engineer (cr Prof.)			1			6					1		1							
	Ph.D.	0	0	4	0		14		3		0	2		1	15	2	7		1	2	4
1984	B.S.	50	33		39	34		20	73	63	35	0	86	37	88	95	105	18	38	18	19
	M.S.	5	5	13	2	7	52		16		10	11		5	25	9	25		4	2	4
	Engineer (or Prof.)			2			4					1									
	Ph.D.	2	0	4	0		19		6		3	2		1	8	8	12		0	1	0
1985	B.S.	59	42		45	35		25	65	75	68	0	115	58	98	126	117	15	33	36	29
	M.S.	5	6	21	7	7	62		20		10	19		9	23	12	24		7	9	7
	Engineer (or Prof.)						2					1									
	Ph.D.	1	0	7	0		14		6		7	4		3	9	4	9		4	3	1
1986 Est-imated	B.S.	56	47		40	40		12	70	59	78	0	110	75	96	131	131	17	36	40	27
	M.S.	5	5	11	6	5	56		17		5	15		10	20	10	25		6	6	8
	Engineer (or Prof.)			3			5		0			0									
	Ph.D.	1	1	3			19		5		2	1		4	11	3	10		4	3	1

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PART I - GENERAL INFORMATION

TABLE 3 (CONTINUED)

6. Number of Degrees in Aeronautics and Aerospace Awarded in the Last Four Calendar Years

Year	Degree	Univ. of Maryland	U.S. Naval Academy	Boston University	Massachusetts Institute of Technology	Univ. of Michigan	Mississippi State Univ.	Parks College of St. Louis University	Univ. of Missouri	Rutgers University	Cornell University	New York Institute of Technology	Rensselaer Polytechnic Institute	State Univ. of New York at Buffalo	Air Force Institute of Technology	Ohio State University	Univ. of Cincinnati	Univ. of Oklahoma	Texas A&M University	Univ. of Texas at Austin	Univ. of Virginia	Virginia Poly. Inst. and St. Univ.
1983	B.S.	50	55	19	72	114	24	47	28		0	12	37	38	27	58	30	20	89	62	31	66
	M.S.	8		2	35	19	2		2	8	3		10	6	57	8	28	1	18	15	1	18
	Engineer (or Prof.)				0						1								0			
	Ph.D.	1			10	9	5		0	3	1		2		3	2	6	2	6	6	0	8
1984	B.S.	24	60	40	74	125	26	68	24		0	10	37	42	30	80	40	25	67	52	29	75
	M.S.	5		1	54	22	10		1	8	1		10	4	45	8	19	2	11	24	1	18
	Engineer (or Prof.)				2						2								0			
	Ph.D.	3			7	10	3		0	4	4		2		2	2	6	1	0	9	2	8
1985	B.S.	55	69	58	88	114	27	90	38		0	10	37	38	28	60	26	15	100	72	37	123
	M.S.	10		5	76	23	3		4	7	3		10	8	52	5	19	0	21	24	4	26
	Engineer (or Prof.)				1						5								0			
	Ph.D.	3			12	10	1		0	3	2		2	1	1	0	4	1	101	6	1	11
1986 Estimated	B.S.	69	55	75	92	98	30	78	50		0	11	30	45	0	65	27	12	100	80	38	130
	M.S.	10		11	76	36	7		2	10	0		12	10	51	13	30	1	15	30	7	26
	Engineer (or Prof.)				0	1					2											
	Ph.D.	8		7	18	13	4			4	0		4	2	2	2	4	0	5	8	1	11

TABLE 3 (CONTINUED)

PART II - BASIC COURSES IN THE UNDERGRADUATE CURRICULUM

		Auburn University	Univ. of Arizona	CA Poly. St. Univ. at San Luis Obispo	San Diego State Univ.	Univ. of California at Davis	Univ. of South. CA	U.S. Air Force Academy	Univ. of Colorado at Boulder	Embry-Riddle Aeron. Univ.	Univ. of Florida at Gainesville	Georgia Institute of Technology	Univ. of Illinois at Urbana-Champ.	Purdue University	Tri-State University	Univ. of Notre Dame	Univ. of Kansas	Wichita State Univ.	Univ. of Maryland
		Number of Semester (or Quarter) Credit Hours																	
1.	Mechanics of Deformable Solids																		
	Strength of Materials (or Solid Mechanics)	R,3 ME	R,3 CE	R,6 CE	R,3 CE E,3	R,3	R,3 CE	R,1½ EM	R,3	R,3	R,3	R,4	R,3 3*	R,3	R,5	R,3	R,3 CE	R,3 E,3	R,3 CE
	Continuum Mechanics (e.g., Elasticity and Inelasticity)	E,3 ME		E,3 ME		E,6		R,1 EM	E,3*	E,3	E,3	R,3				E,1		E,3	
	Others		R,3 CE									R,3				E, 0.5			
2.	Structural Analysis and Structural Stability																		
	Determination of Flight Vehicle Loads and Temperatures	R,3		R,6 AE			R,3 AE	R,3			R,2		R,4		R,1 AE	R,1	R,3	R, 0.5	
	Classical Methods of Structural Analysis	R,2	R,6 E,3	R,4 AE		R,4	*	R,1	E,6*	R,6	R,2 E,3		R,4	R,3	R,2 AE	1.5 CE R,1.5	R,3		R,7 E,1
	Matrix Methods of Structural Analysis				E,3	R,3											R,3		
	(Beams and Frames)	R,3	E,3 CE				*	R,½ E,½CE	R, 0.5		E,3		E,1½	E,2	R,1 AE	R,1 1.5 CE	R,2	R,1	E,1
	(Plates and Shells)						E,3*		E,3*		E,3		E,1½			E, 0.5	R,2		E,1
	Thin-Walled and Stressed Skin Structures (Sheet-Stringer Construction, Shear-Lag)	R,2		R,2 AE	R,3	R,1			R,2	E,3		R,3				R,1		R,2	
	Structural Stability																		
	(Beams and Frames)			E,3 ME			E,3* CE	R,½ E,½CE	E,3*		E,1½	R,3			R,1 AE	R,0.5 1.5 CE	E,6 CE		
	(Plates and Shells)	E,3 ME					E,3* CE		E,3*		E,1½					1.5 CE			
	Plates	E,3 ME					E,3 CE		E,3*		E,3				R,1 AE			E,1	
	Shells	E,3 ME				+	E,3 CE		E,3*		E,3								
	Others																		

AE = Aerospace Engineering
CE = Civil Engineering
E = Electives
EM = Engineering Mechanics
ME = Mechanical Engineering
R = Required
* = Taught by Other Departments
+ = Included in a Course

TABLE 3 (CONTINUED)

PART II - BASIC COURSES IN THE UNDERGRADUATE CURRICULUM

	U.S. Naval Academy	Boston University	Massachusetts Institute of Technology	Univ. of Michigan	Mississippi State Univ.	Parks College of St. Louis University	Univ. of Missouri	New York Institute of Technology	Rensselaer Polytechnic Institute	State Univ. of New York at Buffalo	Air Force Institute of Technology	Ohio State University	Univ. of Cincinnati	Univ. of Oklahoma	Texas A&M University	Univ. of Texas at Austin	Univ. of Virginia	Virginia Poly. Inst. and St. Univ.
	Number of Semester (or Quarter) Credit Hours																	
1. Mechanics of Deformable Solids																		
Strength of Materials (or Solid Mechanics)	R,4 ME	R,4	R, 0.50	R,3 ME	R, 3.0	R,5	R,3 EM	R,4	R,3	R,½	R,4	R,4 EM	R,3	R,3	R,3 CE	R,3	R,3	R,5
Continuum Mechanics (e.g., Elasticity and Inelasticity)		E,4	R, 0.83			E,3	E,3 EM		R,3					E,3	R,1.5 E,3 MM*			
Others																E,3		
2. Structural Analysis and Structural Stability																		
Determination of Flight Vehicle Loads and Temperatures		R,4	R, 0.29		R, 0.1	R,1		R,4		R,½		R,1	R,1		R, 0.5		R, 0.3	R, 1.5
Classical Methods of Structural Analysis	R,3	R,4	R,2.68 3 CE,3 ME,3OE	R,3	R, 0.3	R,3		R,4	R,1		R,5	R,3	R,2	3	R,3 E,3		R, 0.2	R, 1.5
Matrix Methods of Structural Analysis						R, 0.5											R,1	
(Beams and Frames)	E,1	R,1	R,0.5 E,1		R, 1.0	R, 0.5	R,3	E,3	R,1		E,3	R,1	R,2		R,1.5 E,6	R,2	R,1	R,3
(Plates and Shells)	E,2	E,1	E,2		R, 0.5	R, 0.5							R,1					
Thin-Walled and Stressed Skin Structures (Sheet-Stringer Construction, Shear-Lag)	R,3	R,1	R, 0.78	R,1	R, 2.0	R, 0.8	R,3	R,3	R,1	R,1		R,3	R,3		R, 1.5	R,1	R,1	
Structural Stability																	R, 0.5	
(Beams and Frames)		R,½	R, 0.78		R, 0.4		E,3 EM		R,1	R, 0.2		R,2	R,½	E,3		E,3	R, 0.2	E,3
(Plates and Shells)		E,½	R, 0.21	R,1	R, 0.4					R, 0.1		R,2	R,½				R, 0.3	
Plates		E,½		E,3	R, 0.2	R, 0.1				R, 0.1				E,3				
Shells		E,½								R, 0.1				E,3				
Others			R,0.78 E,3															

CE = Civil Engineering
E = Electives
EM = Engineering Mechanics
ME = Mechanical Engineering
MM = Mechanics and Materials courses (administered by Aerospace Engineering Department)

OE = Ocean Engineering
R = Required
* = Taught by Other Departments

TABLE 3 (CONTINUED)

PART II - BASIC COURSES IN THE UNDERGRADUATE CURRICULUM

		Auburn University	Univ. of Arizona	CA Poly. St. Univ. at San Luis Obispo	San Diego State Univ.	Univ. of California at Davis	Univ. of South. CA	U.S. Air Force Academy	Univ. of Colorado at Boulder	Embry-Riddle Aeron. Univ.	Univ. of Florida at Gainesville	Georgia Institute of Technology	Univ. of Illinois at Urbana-Champ.	Purdue University	Tri-State University	Univ. of Notre Dame	Univ. of Kansas	Wichita State Univ.	Univ. of Maryland
		Number of Semester (or Quarter) Credit Hours																	
3.	Structural Dynamics																		
	Analytical Dynamics			R,3 ME	R,3	R,6	R,3 CE	E,3 EM	E,3*		E,3	R,3 ESM	R,2	R,6		E,3		R,3 E,3	
	Dynamics of Discrete Systems																		
	Classical	R,2	R,3 E,3	R,3 ME			E,3 CE	E,6 EM	E,3*	R,3		R,3 ESM			R,3 ME	E,1 1.5 CE	6 CE & ME	E, 0.75	E, 2.4
	Matrix Methods	R,1				E,3	E,3 CE	E,6 EM	E,3*				R,2		R,1 ME	E,1 1.5 CE		E, 0.75	E, 0.1
	Dynamics of Framed Structures																		
	Classical			E,3 AE		E,3	E,3 CE	E,1½ EM	E,3*		E,3					1,CE		E, 0.75	
	Matrix Methods					E,3	E,3 CE	E,1½ EM	E,3*	E,3	E,3			E,1		1,CE		E, 0.75	
	Aircraft Vibrations and Flutter	R,4			R,3			R, 1/20			R,3	R,3	E,3			E, 1.50	E,3	E,3	E, 0.5
	Random Vibrations					E,3	E,3 ME			E,3	E,3		E,3						
	Dynamic Simulation			E,3 ME		R,4	E,3 ME												
	Others		E,3															R,3	
4.	Experimental Stress Analysis																		
	Measurements and Instrumentation	R,8 EE	R,3	R,1 AE	R,1 CE	R,1	R,3	R,½	E,3*	R,3	E,3	R,2	R,½	R,1	R,4 ME;E, 3,ES	R, 0.50 E,1	E,2 CE	R,1 6*	E,1
	Structural Testing of Components of Flight Vehicles		R,1					E,3 EM				R,2	R,½	R,1		R, 0.50		R, 0.5	E,½
	Structural Dynamics Lab						E,3 CE	E,1½ EM			E,3		R,½						
	Photoelasticity	E,3 ME					E,3 ME	E,1/5 EM			E,6		R,½		E,1		E,1 CE		
	Others							E,1/10 EM											
5.	Materials for Flight Structures and Methods of Construction																		
	Metallic Materials (including Lab)	R,2		R,3 MET			E,3 Mat Sc & ME	E,3 EM	E,2*	R,3	E,2				R,3 E,4 ME	R,1	R,2	R,4 4*	

AE = Aerospace Engineering
CE = Civil Engineering
E = Electives
EE = Electrical Engineering

EM = Engineering Mechanics
ES = Engineering Science
ESM = Engineering Science and Mechanics
Mat Sc = Materials Science

ME = Mechanical Engineering
MET = Metallurgy
R = Required
* = Taught by Other Departments

TABLE 3 (CONTINUED)

PART II - BASIC COURSES IN THE UNDERGRADUATE CURRICULUM

		U.S. Naval Academy	Boston University	Massachusetts Institute of Technology	Univ. of Michigan	Mississippi State Univ.	Parks College of St. Louis University	Univ. of Missouri	New York Institute of Technology	Rensselaer Polytechnic Institute	State Univ. of New York at Buffalo	Air Force Institute of Technology	Ohio State University	Univ. of Cincinnati	Univ. of Oklahoma	Texas A&M University	Univ. of Texas at Austin	Univ. of Virginia	Virginia Poly. Inst. and St. Univ.
		Number of Semester (or Quarter) Credit Hours																	
3.	Structural Dynamics																		
	Analytical Dynamics		E	R,3		E,1	R,3	E,3		E,1			E,4	R,3		R,3			
	Dynamics of Discrete Systems						R, 0.2												
	Classical	E, 1½	R	R,0.14 E,3		E, 0.5	R,1 E,3		R,3	E,1	R,1	R,3	R,4 EM	R,3	R,3	R, 1.5	R,1		R,3
	Matrix Methods	E, 1½	E			E, 0.5	R, 1.6			E,1							R,1		E,3
	Dynamics of Framed Structures																		
	Classical		R						E,3							E, 1.5			
	Matrix Methods		E					E,3 CE								E, 1.5	R,1		
	Aircraft Vibrations and Flutter				R,1	E,1	E,3	E,3		E,2	E,1		R,1			E,3			
	Random Vibrations						R, 0.2							E,3					
	Dynamic Simulation		E								R,1			R,3					
	Others																		
4.	Experimental Stress Analysis																		
	Measurements and Instrumentation		R,4				R,2	R,3	R,2 E,3	R,2 E,3	R,1	R,1	R,1 EM	R,2	E,2	R,1	R,3		
	Structural Testing of Components of Flight Vehicles	R,1				R, 0.5	R,1									R, 0.5	R,1		
	Structural Dynamics Lab					R, 0.5				E,3		R,1	R,1			R, 0.5			
	Photoelasticity							E,6 EM		E,1				E,3					
	Others														E,2				
5.	Materials for Flight Structures and Methods of Construction																		
	Metallic Materials (Including Lab)	R,4 ME		R, 2.5		R, 0.3		R,3 Metl	R,3		R,1	E,3	R,2 Metl			R,1	R,2	1.0 ME	R, 1.5

CE = Civil Engineering
E = Electives
EM = Engineering Mechanics
Metl = Metallurgy
ME = Mechanical Engineering
R = Required

TABLE 3 (CONTINUED)

PART II - BASIC COURSES IN THE UNDERGRADUATE CURRICULUM

		Auburn University	Univ. of Arizona	CA Poly. St. Univ. at San Luis Obispo	San Diego State Univ.	Univ. of California at Davis	Univ. of South. CA	U.S. Air Force Academy	Univ. of Colorado at Boulder	Embry-Riddle Aeron. Univ.	Univ. of Florida at Gainesville	Georgia Institute of Technology	Univ. of Illinois at Urbana-Champ.	Purdue University	Tri-State University	Univ. of Notre Dame	Univ. of Kansas	Wichita State Univ.	Univ. of Maryland
		Number of Semester (or Quarter) Credit Hours																	
5.	Materials for Flight Structures and Methods of Construction																		
	Nonmetallic Materials (including Fibrous Composites)			E,3 AE	E,3 ME	E,3		E,1 EM	E,1*	E,3	E,6	E,3	E,3 3*	E,3	R,1 ME E,4 ES	R,1	E,3 AE	R,1 E,3	E,3
	Fatigue, Fracture and Life Prediction				E,3			E,½ EM				E,3		E,3	R,1 AE	R, 0.5	E,3 CE/AE	R,1	
	Fabrication Techniques			E,3 AE				E,1 EM			E,2					R, 0.5			
	Others	R,2																	
6.	Aeroelasticity and Aeroinelasticity																		
	Basic Course (Classical Aeroelasticity)				R,2			R,½			E,3		E,3	E,3	E,4 AE	E,3	E,3 AE		
7.	Structural Design																		
	The Organization of Design	R,1		R,2 AE		+	E,3 CE/ME	R,3 E,3EM	E,3*	R,3	R,3	R,4	R,1			R, 0.25	E,3 AE	R, 0.25	
	Fully-Stressed and Fail-Safe Design						E,3 CE/ME										E,3	R, 0.25	
	Optimization Techniques						E,3 CE/ME		E,3*		E,3					E,3	E,3		
	Applications to:																		
	Aircraft			R,3 AE		R,4	E,3 CE/ME	R,3			R,3					R, 0.25	E,2		
	Rotorcraft						E,3 CE/ME												
	Spacecraft			R,3 AE			E,3 CE/ME	E,3									E,1		
	Large Space Structures						E,3 CE/ME	E,3											
	Design Project	R,2		R,3 AE	R,5		R,3	R,1½; E3;1½ EM	E,3*			R,4	R,2	R,3 E,3		R, 0.50	E,3	R,1	
	Others		R,3																

AE = Aerospace Engineering
CE = Civil Engineering
E = Electives
EM = Engineering Mechanics
ES = Engineering Science
ME = Mechanical Engineering
R = Required
* = Taught by Other Departments
+ = Included in a Course

TABLE 3 (CONTINUED)

PART II - BASIC COURSES IN THE UNDERGRADUATE CURRICULUM

		U.S. Naval Academy	Boston University	Massachusetts Institute of Technology	Univ. of Michigan	Mississippi State Univ.	Parks College of St. Louis University	Univ. of Missouri	New York Institute of Technology	Rensselaer Polytechnic Institute	State Univ. of New York at Buffalo	Air Force Institute of Technology	Ohio State University	Univ. of Cincinnati	Univ. of Oklahoma	Texas A&M University	Univ. of Texas at Austin	Univ. of Virginia	Virginia Poly. Inst. and St. Univ.
		Number of Semester (or Quarter) Credit Hours																	
5.	Materials for Flight Structures and Methods of Construction																		
	Nonmetallic Materials (including Fibrous Composites)		E,4	R, 0.5 E,1		R, 0.1	E,3	E,3 EM		E,6	R,½		R,1 Metl		E,3	R,1	E,3	E,1 1 ME	E,3
	Fatigue, Fracture and Life Prediction			R, 0.35		R, 0.2	R, 0.1	E,3 EM		E,1	E,1		R,1 Metl		E,3	R,1		E,0.5 0.5, ME	R, 1.5
	Fabrication Techniques									E,3								E,0.5 0.5 ME	
	Others														R,3				
6.	Aeroelasticity and Aeroinelasticity																		
	Basic Course (Classical Aeroelasticity)	E,3	E,4				E,3	E,3 EM	R,3	E,3			E,4		E,3	E,3	E,3		
7.	Structural Design																		
	The Organization of Design			R, 0.6	E,3 3 ME	R, 0.4		R,1							E,3		R,1	R,1	
	Fully-Stressed and Fail-Safe Design			R, 0.07		R, 0.4							R,4						
	Optimization Techniques					R, 0.2					E,1							R, 0.5	
	Applications to:																		
	Aircraft		R,4	R, 0.60		R, 1.0	R,3		R,4				R	R,5	R,3		R,1	R, 0.5	
	Rotorcraft		E,4										R						
	Spacecraft		E,4						E,4				R				E,3		
	Large Space Structures																		
	Design Project		R,2		R,3 3*	R, 0.5	R,1	R,3	R,4		R,1					R,1 E,3	R,1	R,1	R,9
	Others																		

E = Electives
EM = Engineering Mechanics
ME = Mechanical Engineering
Metl = Metallurgy

R = Required
* = Taught by Other Departments

TABLE 3 (CONTINUED)

PART II - BASIC COURSES IN THE UNDERGRADUATE CURRICULUM

		Auburn University	Univ. of Arizona	CA Poly. St. Univ. at San Luis Obispo	San Diego State Univ.	Univ. of California at Davis	Univ. of South. CA	U.S. Air Force Academy	Univ. of Colorado at Boulder	Embry-Riddle Aeron. Univ.	Univ. of Florida at Gainesville	Georgia Institute of Technology	Univ. of Illinois at Urbana-Champ.	Purdue University	Tri-State University	Univ. of Notre Dame	Univ. of Kansas	Wichita State Univ.	Univ. of Maryland
		Number of Semester (or Quarter) Credit Hours																	
8.	Computational Mechanics and CAD/CAM																		
	Introduction to Numerical Methods (Linear Algebraic Equations, Eigenvalue Extraction, etc.)	R,4	R,3	E,3 CSc	E,3	R,3	R,2	E,6 Math	E,3*		R,3		R,3 3*			R, 1.5		R,1 E,2 1*	
	Computer Programming (Fortran, Basic, Others)	R,3	R,3 E,3	R,2 Eng	R,2 E,3	R,4	R,2	R,1 E,3 Math	R,3*	R,3	R,2	R,3	R,3 3*	R,2	R,3 CS	R, 1.5	R,3 CS	R,2	R,3 EE
	Advanced Numerical Methods		R,3		E,3	E,3	E,3 CE/ME	R,3	E,6*		R,3				E,4 Math			E,8 8*	
	Finite-Difference Methods				E,3	E,3	E,3 CE	E,3 EM			R,1								
	Finite Element Methods (for Two- and Three-Dimensional Structures)	R,2	R,3	E,2 AE	E,3	E,6	E,3 CE	R,½ E,3 EM	R, 0.5	E,3	R,1 R,6		E,3	E,3	R,1 AE E,4	5 CE	E,4 AE	R,1	E,3
	Computer Graphics				E,3		E,3 CE/ME			E,3 CS	R,1*			3 ME		E, 1.5	R,1	R,3	
	Computer-Aided Design			E,2 ETME	E,3		E,3 ME		E,3*		*					E, 1.5	E,3		
	Computer-Aided Manufacturing										*								
	Others																		
9.	Multidisciplinary Design (Integration of Structures with Other Disciplines)																		
	Propulsion			E,4 AE	R,3 E,3	R,3	R,3 ME	E, 1/5					R,3						
	Controls (Passive and Active)			R,6 AE	R,3	R,4	**	E, 1/2					R,3						
	Aerodynamics	R,15		R,9 AE	R,6	R,8	**	R,3		R,3			R,8						
	Propulsion Systems					R,4	**	R, 1/5		R,3	R,6						R,8		
	Thermodynamics	R,3 ME		R,5 AE	R,3	R,6	**						R,3 3*						
	Flight Mechanics	R,3		E,3 AE	R,3	R,4	**			R,3			E,3						
	Others		R,3			R,4												R, 0.5	

AE = Aerospace Engineering
CE = Civil Engineering
CSc (or CS) = Computer Science
E = Electives
EE = Electrical Engineering

Eng = Engineering
EM = Engineering Mechanics
ETME = Engineering Technology/Mechanics
Math = Mathematics
ME = Mechanical Engineering

R = Required
* = Taught by Other Departments
** = No Formal Integration with Structures

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TABLE 3 (CONTINUED)

PART II - BASIC COURSES IN THE UNDERGRADUATE CURRICULUM

		U.S. Naval Academy	Boston University	Massachusetts Institute of Technology	Univ. of Michigan	Mississippi State Univ.	Parks College of St. Louis University	Univ. of Missouri	New York Institute of Technology	Rensselaer Polytechnic Institute	State Univ. of New York at Buffalo	Air Force Institute of Technology	Ohio State University	Univ. of Cincinnati	Univ. of Oklahoma	Texas A&M University	Univ. of Texas at Austin	Univ. of Virginia	Virginia Poly. Inst. and St. Univ.
		Number of Semester (or Quarter) Credit Hours																	
8.	Computational Mechanics and CAD/CAM																		
	Introduction to Numerical Methods (Linear Algebraic Equations, Eigenvalue Extraction, etc.)	E,3 Math	R,2	E,3	E,3 3 Math		R,1 Math	E,3 CS	R,3	R,2 3 Math	R,1		R,4		R,3	R,3	R,2 3*		E,3
	Computer Programming (Fortran, Basic, Others)	R,1 E,3 Math	R,4	E,3 CE E,3 ME	R,2 3 ECE		R,3 Math	R,3 CS	R,3	R,1 2 CS	R,1		R,3 EngGr	R,3	R,2	R,2	R,1 E,3	R,3 9 CS	E,7
	Advanced Numerical Methods		R,4				E,3 Math	E,3 CS		E,3	R,1		E,4	R,4		E,3	R,2	3 Ap Math	
	Finite-Difference Methods		E,4					E,3 EM			R, 0.2							E,3	
	Finite Element Methods (for Two- and Three-Dimensional Structures)	E,3	E,4		3*		R, 0.5	R,3		E,3	R, 0.2		E,4		E,3		E,3	E,3	E,3
	Computer Graphics	E,3	R,4					E,3		R,1	E,½					E,3*	3*	R,1 E,3	
	Computer-Aided Design	E,3	R,4		E,3 6 ME			E,3		E,3	E,1				E,3		3*	R,1 2 Eng	
	Computer-Aided Manufacturing	E,3	E,4		3 ME						E,1							1 Eng	
	Others																		
9.	Multidisciplinary Design (Integration of Structures with Other Disciplines)																		
	Propulsion			R, 0.4				R,3	R,3	R,3						R, 0.5			R,3
	Controls (Passive and Active)		E,4	R, 0.8			R,1	R,3		R,3 E,3 EL	R,1		R,4	R,6	R,3	R, 0.5			R,3
	Aerodynamics			R, 0.8			R,1	R,3	R,3	R,3	R,1			R,13		R,1	R,1	R,1	R,10
	Propulsion Systems			R, 0.4			R,1	R,3			R,1			R,6			R,1	R,1	
	Thermodynamics							R,3	R,3	R,6	R,1			R,3					
	Flight Mechanics		E,4	R, 0.8			R,1	R,3	R,3	R,3	R,1		E,4	R,3		R,1	R,1	R,1	
	Others					R,3		R,3				R,6							

ApMath = Applied Mathematics
CE = Civil Engineering
CS = Computer Science
E = Electives
ECE = Electrical and Computer Engineering
EL = Flectrical Engineering
Eng = Engineering

EngGr = Engineering Graphics
EM = Engineering Mechanics
Math = Mathematics
ME = Mechanical Engineering
R = Required
* = Taught by Other Departments

TABLE 3 (CONTINUED)

PART III - BASIC COURSES IN THE GRADUATE CURRICULUM

		Auburn University	Univ. of Arizona	California Institute of Technology	CA Poly. St. Univ. at San Luis Obispo	San Diego State Univ.	Stanford University	Univ. of South. CA	Univ. of Colorado at Boulder	GWU (JIAFS)	Univ. of Florida at Gainesville	Georgia Institute of Technology	Univ. of Illinois at Urbana-Champ.	Purdue University	Univ. of Notre Dame	Univ. of Kansas	Wichita State Univ.
		Number of Semester (or Quarter) Credit Hours															
1.	Mechanics of Deformable Solids																
	Advanced Strength of Materials (or Advanced Solid Mechanics)	3 AE	3 CE		3 AE	3 AE	3 CE 3 ME	6 CE/ME	2*	3 ES	6 AE	3 ESM			3 AE	3 CE	3 AE
	Theory of Elasticity	3 ME	3 EM	6 AM		3 AE	9 ME	6 CE/ME	2*	6 ES	3 AE	6 ESM		3 AE		3 CE	
	Applied Elasticity			3 AE				6 CE/ME	1*			6 ESM		3 CE		3 CE	3 AE
	Theory of Plasticity		3 EM	3 AE		3 AE	6 ME 3 Mat	6 CE	1*	3 ES	9 AE	3 ESM		3 CE 3 AE		3 CE	3 AE
	Viscoelasticity			1 AE			6 ME	3 Ch Eng	1*		3 AE		3 AE	3 CE		3 CE	
	Nonlinear Continuum Mechanics		3 EM				6 ME 3 Mat	6 CE/ME		3 ES			3 AE		1.5 CE		
	Thermoelasticity										3 AE	3 AE	6		3 AE		
	Wave Propagation in Solids			3 AM			3 Math 6 ME	9 CE/ME			3 AE	3 ESM		3 AE			3 AE
	Variational and Energy Methods in Mechanics				3 AE	3 AE	3 Math	6 CE/ME		3 ApSc		3 AE 3 ESM					1 AE
	Others			3 AE													
2.	Structural Analysis and Structural Stability																
	Thin-Walled and Stressed Skin Structures (Sheet-Stringer Construction)				3 AE		6 AA	3 AE		3 ES						3 AE	
	Structural Stability		3 CE	1 AE	3 ME		3 AA; 3 CE; 3ME	3 CE	1*	3 CE	3 AE	6 AE		3 CE	3 AE	3 CE	1.5 AE
	Theory and Analysis of Plates	3 ME	3 EM	1 AE	3 ME	3 AE	3 ME	3 CE	1*	3 CE	3 AE	3 ESM	3 EM 3*	3 CE	1.5 CE	3 CE	1 AE
	Theory and Analysis of Shells	3 ME		1 AE		3 AE	6 ME	3 CE	1*		3 AE	3 ESM	3 EM 3*	3 AE	1.5 CE	3 CE	
	Others	3 AE															
3.	Structural Dynamics																
	Analytical Dynamics	R,5	3 AE	1 AM	3 AE	3 AE	3 AA 3 ME	6 CE	1*	3 ES	6 AE	6 AE		3 ME	3 CE	3 AE	3 AE
	Dynamics of Framed Structures		3 EM			3 CE	3 AE 6 CE		1*	3 ME	3 AE				3 CE		3 AE

AA = Aeronautics and Astronautics
AE = Aeronautical Engineering
AM = Applied Mechanics
ApSc = Applied Science
CE = Civil Engineering
Ch = Chemical Engineering
Eng = Engineering
EM = Engineering Mechanics
ES = Engineering Science
ESM = Engineering Science and Mechanics
Mat = Materials
Math = Mathematics
ME = Mechanical Engineering
R = Required
* = Taught by Other Departments

TABLE 3 (CONTINUED)

PART III - BASIC COURSES IN THE GRADUATE CURRICULUM

		Univ. of Maryland	Boston University	Massachusetts Institute of Technology	Univ. of Michigan	Univ. of Missouri	Rutgers University	Cornell University	Rensselaer Polytechnic Institute	State Univ. of New York at Buffalo	Air Force Institute of Technology	Ohio State University	Univ. of Cincinnati	Univ. of Oklahoma	Texas A&M University	Univ. of Texas at Austin	Univ. of Virginia	Virginia Poly. Inst. and St. Univ.
		Number of Semester (or Quarter) Credit Hours																
1.	Mechanics of Deformable Solids																	
	Advanced Strength of Materials (or Advanced Solid Mechanics)		1 AE	6 OE		3 AE	3 AE 3 MMS	3 AE 3*		3 AE	3 AE	3 ME	3 AE			6 AE/EM	3 AE	
	Theory of Elasticity	3 ME 1 AE			3 AM	6 EM	3 MMS	3*	6 AE	3 AE	4 AE	3 AE	3 AE	3 AE	6 MM*		0.5 AE	6 ESM
	Applied Elasticity	3 ME	1 AE	3 ME	3 AM	3 EM		3*		3 AE	4 AE	3 AE		3 AE	3 MM	3 EM	0.5 AE	6 ESM
	Theory of Plasticity	3 ME	1 AE	2 AE; 3 ME; 3 OE	3 AM	6 EM	3 MMS	3*	3 AE	3 AE	4 AE	3 AE	3 AE	3 AE	3 MM	3 EM	0.5 AE	6 ESM
	Viscoelasticity			1 AE	3 AM	3 EM			3 AE	3 AE		3 AE			6 MM	3 EM	0.5 AE	3 ESM
	Nonlinear Continuum Mechanics	3 ME		3 ME				1.5 AE	3 AE	3 AE		3 AE	3 AE		1.5 MM	6 EM	0.5 AE	3 ESM
	Thermoelasticity			½ AE		3 AE	3 MMS	0.5 AE		3 AE		3 AE	3 AE		3 MM		0.5 AE	
	Wave Propagation in Solids		1 AE	3 ME		6 EM		3*	3 AE	3 AE	4 AE	3 AE		3 AE	3 MM	6 EM		
	Variational and Energy Methods in Mechanics	2 AE	1 AE		3 AM	3 EM		3*		3 AE	4 AE	3 AE	6 AE	3 AE	3 MM	3 AE	3 AE	
	Others																	
2.	Structural Analysis and Structural Stability																	
	Thin-Walled and Stressed Skin Structures (Sheet-Stringer Construction)					3 AE	3 AE		1 AE			3 AE						3 AE
	Structural Stability	3 AE	1	1 AE	3 AE	6 EM		3*	3 AE	3 AE	4 AE	3 AE	3 AE	3 AE	3 MM	3 EM	3 AM	9 AE
	Theory and Analysis of Plates		1 AE	1½ AE	3 AE	3 EM	3 CE	3*	2 AE	3 AE	4 AE	3 AE	3 AE	3 AE	3 MM	1 EM		3 ESM
	Theory and Analysis of Shells		1 AE	3 AE		3 EM	3 CE	3*	1 AE	3 AE	4 AE	3 AE	3 AE	3 AE	3 MM	2 EM	3 AM	3 ESM
	Others																	
3.	Structural Dynamics																	
	Analytical Dynamics	3 AE			4 AE	6 AE	3 AE	3*		3 AE	4 AE	3 AE			3 ME	3 EM	3 AE	2 AE 6 ESM
	Dynamics of Framed Structures					3 CE			3 CE	1*		3 AE			3 ME	3 AE	0.5 AE	

AE = Aerospace Engineering
AM = Applied Mechanics
CE = Civil Engineering
EM = Engineering Mechanics

ESM = Engineering Science and Mechanics
ME = Mechanical Engineering
MM = Mechanics and Materials (under direction of Aerospace Engineering Dept.)

MMS = Mechanics and Materials Science
OE = Ocean Engineering
* = Taught by Other Departments

TABLE 3 (CONTINUED)

PART III - BASIC COURSES IN THE GRADUATE CURRICULUM

		Auburn University	Univ. of Arizona	California Institute of Technology	CA Poly. St. Univ. at San Luis Obispo	San Diego State Univ.	Stanford University	Univ. of South. CA	Univ. of Colorado at Boulder	GWU (JIAFS)	Univ. of Florida at Gainesville	Georgia Institute of Technology	Univ. of Illinois at Urbana-Champ.	Purdue University	Univ. of Notre Dame	Univ. of Kansas	Wichita State Univ.
		Number of Semester (or Quarter) Credit Hours															
3.	Structural Dynamics																
	Dynamics of Plates and Shells			1 AM				3 CE	1*	1*	3 AE						1 AE
	Random Vibrations		3 AE	1 AM	3 ME		3 AA 3 CE	6 ME	1*	3 ES	3 AE	6 ESM	3 AE				3 AE
	Nonlinear Vibrations	3 ME		3 AM	3 ME		3 ME	3 ME			3 AE	6 ESM		3 ME			
	Dynamics of Space Vehicles	3 AE			3 AE		6 AA		1 AE				3 AE			3 AE	
	Dynamics of Rotating Machinery	3 ME														ME	
	Others	3 AE	3 AE														
4.	Experimental Stress Analysis																
	Advanced Methods of Experimental Stress Analysis	3 ME		2 AE		3 ME	6 ME				3 AE	6 AE		6 AE		3 CE	
	Others	1 AE									6 AE						
5.	Materials for Flight Structures and Methods of Construction																
	Metallic Materials (including Lab)		4 AE				12 Mat	3 ME			3 AE						
	Fibrous Composites				4 AE		3 AA	3 AE/CE	1*	3 ES	3 AE	3 AE	3 AE 3*	3 AE		3 AE	3 AE
	Fatigue, Fracture and Life Prediction						21 Mat 3 ME	3 AE				3 AE 3 ESM		6 AE 3 ME	3 AE	3 AE	7.5 AE 6*
	Others		3 AE				3 Mat										
6.	Aeroelasticity and Aeroinelasticity																
	Basic Course (Classical Aeroelasticity)	3-5 AE					3 AA	3 AE		3 ES	3 AE		3 AE	3 AE	3 AE	3 AE	
	Advanced Course	3-5 AE					3 AA	3 AE		3 ES		3 AE					1.5 AE
	Unsteady Aerodynamics							3 AE		3 ME		3 AE		3 AE			1.5 AE
	Others											3 AE					

AA = Aeronautics and Astronautics
AE = Aerospace Engineering
AM = Applied Mechanics
CE = Civil Engineering
ES = Engineering Science
ESM = Engineering Science and Mechanics
Mat = Materials
ME = Mechanical Engineering
* = Taught by Other Departments

TABLE 3 (CONTINUED)

PART III - BASIC COURSES IN THE GRADUATE CURRICULUM

		Univ. of Maryland	Boston University	Massachusetts Institute of Technology	Univ. of Michigan	Univ. of Missouri	Rutgers University	Cornell University	Rensselaer Polytechnic Institute	State Univ. of New York at Buffalo	Air Force Institute of Technology	Ohio State University	Univ. of Cincinnati	Univ. of Oklahoma	Texas A&M University	Univ. of Texas at Austin	Univ. of Virginia	Virginia Poly. Inst. and St. Univ.
		Number of Semester (or Quarter) Credit Hours																
3.	Structural Dynamics																	
	Dynamics of Plates and Shells		1 AE					3*	1 AE	3 AE	4 AE	3 AE			0.5 MM		0.5 AE	
	Random Vibrations	3 AE		3 ME	3 AM	3 EM	3 AE	3 AE	3 CE	3*			3 AE			3 EM	0.5 AE	3 ESM
	Nonlinear Vibrations			3 ME 3 OE	3 AM	3 EM		3*		3 AE		3 AE	6 AE	3 AE		3 EM	0.5 AE	3 ESM
	Dynamics of Space Vehicles	3 AE				3 AE			3 AE		4 AE	3 AE						3 ESM
	Dynamics of Rotating Machinery		1 AE	3 AE 3 ME			3 AE	3 AE	6 AE	3 AE			3 AE		3 ME		6 AE	
	Others			3 AE										3 AE		3 AE		3 EE
4.	Experimental Stress Analysis																	
	Advanced Methods of Experimental Stress Analysis		2 AE			3 EM	3 AE	3*		3 AE			6 AE	3 AE	6 MM	3 EM		6 ESM
	Others																	
5.	Materials for Flight Structures and Methods of Construction																	
	Metallic Materials (including Lab)		1 AE			3 EM		3*						3*	3 MM			
	Fibrous Composites	3 AE	1 AE	+	3 AE	3 EM	3 MMS	3 AE	6 AE	3 AE	8 AE		3 AE	3 AE	15 MM	3 AE		18 ESM
	Fatigue, Fracture and Life Prediction			3 AE 3 MS&E 3 ME		3 EM	3 MMS	1.5 AE		3 AE	4 AE			3 AE	3 MM 6 ME	3 AE		6 ESM
	Others										4 AE			3 AE				
6.	Aeroelasticity and Aeroinelasticity																	
	Basic Course (Classical Aeroelasticity)	3 AE	1 AE	3 AE	3 AE	3 AE			3 AE		4 AE	3 AE		3 AE	4 AE	3 AE	3 AE	3 AE
	Advanced Course		1 AE									3 AE				3 AE		3 AE
	Unsteady Aerodynamics		1 AE	3 AE					3 AE						3 AE	3 AE		
	Others			3 AE														

AE = Aerospace Engineering
AM = Applied Mechanics
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EE = Electrical Engineering
EM = Engineering Mechanics

ESM = Engineering Science and Mechanics
MS&E = Materials Science and Engineering
ME = Mechanical Engineering
MM = Mechanics and Materials
MMS = Mechanics and Materials Science

OE = Ocean Engineering
* = Taught by Other Departments
+ = Included in a Course

TABLE 3 (CONTINUED)

PART III - BASIC COURSES IN THE GRADUATE CURRICULUM

		Auburn University	Univ. of Arizona	California Institute of Technology	CA Poly. St. Univ. at San Luis Obispo	San Diego State Univ.	Stanford University	Univ. of South. CA	Univ. of Colorado at Boulder	GWU (JIAFS)	Univ. of Florida at Gainesville	Georgia Institute of Technology	Univ. of Illinois at Urbana-Champ.	Purdue University	Univ. of Notre Dame	Univ. of Kansas	Wichita State Univ.
		Number of Semester (or Quarter) Credit Hours															
7.	Structural Design																
	Optimization Techniques						3 ME		1*	3 ES	3 AE	3 AE		3 ME	3 AE	3 AE	
	Applications to:																
	Aircraft	3 AE					6 AA			½*						2 AE	
	Rotorcraft	3 AE					1 AA					3 AE					
	Spacecraft	3 AE								½*						1 AE	
	Large Space Structures													3 AE			
	Design Project	1-5 AE					18 ME		1*			3 AE					
	Others		3 AE				3 ME									5 AE	
8.	Computational Mechanics and CAD/CAM																
	Advanced Programming Techniques and Database Management						7 CE			6 CS	3 AE				6 EE		
	Matrix Methods of Structural Analysis	3 AE	3 EM	1 AE	3 AE	3 AE	3 CE		1*						3 CE	CE	
	Finite Element Methods (for Two- and Three-Dimensional Structures)		3 AE	1 AE	1 ME	3 CE	3 CE		2*	3 ES	3 AE		3 AE	3 AE 3 CE	3 CE	CE	1.5 AE
	Mathematical Theory of Finite Elements			1 AE			6 ME			1*	3 AE					CE	1.5 AE
	Advanced Topics in Finite Element Technology (Nonlinear Problems, Generalized Variational Methods, ... etc.)	6 AE	3 AE	1 AE			3 ME			3 ES						CE	
	Finite Element Modeling			1 AE												AE/CE	1 AE
	Computer-Aided Design		3 AE				6 ME				3 AE	3 AE					
	Computer-Aided Manufacturing						6 ME 6 CS										
	Others																

AA = Aeronautics and Astronautics
AE = Aerospace Engineering
CE = Civil Engineering

CS = Computer Science
EE = Electrical Engineering
EM = Engineering Mechanics

ES = Engineering Science
ME = Mechanical Engineering
* = Taught by Other Departments

TABLE 3 (CONTINUED)

PART III - BASIC COURSES IN THE GRADUATE CURRICULUM

		Univ. of Maryland	Boston University	Massachusetts Institute of Technology	Univ. of Michigan	Univ. of Missouri	Rutgers University	Cornell University	Rensselaer Polytechnic Institute	State Univ. of New York at Buffalo	Air Force Institute of Technology	Ohio State University	Univ. of Cincinnati	Univ. of Oklahoma	Texas A&M University	Univ. of Texas at Austin	Univ. of Virginia	Virginia Poly. Inst. and St. Univ.
		Number of Semester (or Quarter) Credit Hours																
7.	Structural Design																	
	Optimization Techniques				3 AE		3 AE	3 AE	1 AE 3 CE	3*		3 AE				6 AE	0.5 ME	6 AE
	Applications to:																	
	Aircraft		1 AE						1 AE			+						+
	Rotorcraft		1 AE						1 AE			+						+
	Spacecraft		1 AE									+						+
	Large Space Structures																	
	Design Project							1.5 AE	1 AE				3 AE					3 AE
	Others																0.5 ME	
8.	Computational Mechanics and CAD/CAM																	
	Advanced Programming Techniques and Database Management		1*	3 CE				3*		3*		3 CIS						3 CS
	Matrix Methods of Structural Analysis		1 AE			3 AE	3 AE	3*		3*		3 AE		3 CE			3 CE	
	Finite Element Methods (for Two- and Three-Dimensional Structures)		1 AE	3 AE 6 ME 3 CE	3 AE	3 EM	3 CE	6*	6 CE	3 AE 3*	8 AE	3 AE	6 AE	3 AE	3 MM 3 ME	3 EM	3 AE 3 CE	6 AE
	Mathematical Theory of Finite Elements	3 AE	1*		3 ME	3 EM	3 MMS	3*	3 Math		4 AE	3 AE			3 MM 3 Math	6 EM		
	Advanced Topics in Finite Element Technology (Nonlinear Problems, Generalized Variational Methods, ... etc.)	3 AE	1*	3 AE	3 AE 3 ME	3-6*		3*	3 AE			3 AE			3 MM	12 EM	3 AE	
	Finite Element Modeling		1*		3*		3 AE 3 MMS	3 AE	3 AE	3 AE						3 AE	3 AE 3 EE	
	Computer-Aided Design		1 AE	3 ME	6 ME	3 AE	6 AE	3 AE						3 AE		3 ME		
	Computer-Aided Manufacturing		1*	3 AE 3 ME	3 ME			3 AE		3 AE						3 ME		
	Others			3 CE; 3 CE; 3Ma													3 CE	

AE = Aerospace Engineering
CE = Civil Engineering
CIS = Computer and Information Science
CS = Computer Science

EE = Electrical Engineering
EM = Engineering Mechanics
Math (or Ma) = Mathematics
ME = Mechanical Engineering

MM = Mechanics and Materials
MMS = Mechanics and Materials Science
* = Taught by Other Departments
\+ = Included in a Course

TABLE 3 (CONTINUED)

PART III - BASIC COURSES IN THE GRADUATE CURRICULUM

		Auburn University	Univ. of Arizona	California Institute of California	CA Poly. St. Univ. at San Luis Obispo	San Diego State Univ.	Stanford University	Univ. of Southern CA	Univ. of Colorado, Boulder	GWU (JIAFS)	Univ. of Florida, Gainesville	Georgia Institute of Technology	Univ. of Illinois at Urbana-Champ.	Purdue University	Univ. of Notre Dame	Univ. of Kansas	Wichita State Univ.
		Number of Semester (or Quarter) Credit Hours															
9.	Multidisciplinary Design (Integration of Structures with Other Disciplines)																
	Propulsion	6 AE		6 ME	4 AE							3 AE					
	Controls (Passive and Active)	6 AE		6 AM/EE						3 ME		3 AE					
	Aerodynamics	15 AE		10-12 AE; 3-5 ME	3 AE					3 ME		3 AE	6 AE				
	Others	6 AE										3 AE					

AE = Aerospace Engineering
AM = Applied Mechanics
EE = Electrical Engineering
ME = Mechanical Engineering

TABLE 3 (CONTINUED)

PART III - BASIC COURSES IN THE GRADUATE CURRICULUM

		Univ. of Maryland	Boston University	Massachusetts Institute of Technology	Univ. of Michigan	Univ. of Missouri	Rutgers University	Cornell University	Rensselaer Polytechnic Institute	State Univ. of New York at Buffalo	Air Force Institute of Technology	Ohio State University	Univ. of Cincinnati	Univ. of Oklahoma	Texas A&M University	Univ. of Texas at Austin	Univ. of Virginia	Virginia Poly. Inst. and St. Univ.
		Number of Semester (or Quarter) Credit Hours																
9.	Multidisciplinary Design (Integration of Structures with Other Disciplines)																	
	Propulsion			3 AE				3 AE		3 AE		6 AE	6 AE					
	Controls (Passive and Active)		1 AE	3 AE	3 AE			3 AE		3 AE			6 AE			3 AE	18 AE	
	Aerodynamics						3 AE	9 AE		3 AE			12 AE				9 AE 3 AM	
	Others						3 AE											

AE = Aerospace Engineering
AM = Applied Mechanics

TABLE 3 (CONTINUED)

PART IV - EDUCATIONAL AIDS

		Auburn University	Univ. of Arizona	California Institute of Technology	CA Poly St. Univ. at San Luis Obispo	San Diego State Univ.	Stanford University	Univ. of California at Davis	Univ. of South. CA	U.S. Air Force Academy	Univ. of Colorado at Boulder	GWU (JIAFS)	Embry-Riddle Aeron. Univ.	Univ. of Florida at Gainesville	Georgia Institute of Technology	Univ. of Illinois at Urbana-Champ.	Purdue University	Tri-State University	Univ. of Notre Dame	Univ. of Kansas	Wichita State Univ.	Univ. of Maryland
1.	Experimental Facilities and Models for Structures	•	•		•	•			•	•	•	•	•	•	•		•		•	•	•	
2.	Computer-Aided Instruction		•		•						•	•		•	•							
	Applying Microcomputers to Structures Education	•									•	•	•		•		•		•			
	Hands-on Experience				•							•	•	•	•							
3.	Use of Large-Scale Computer Codes	ACSL, NAST-RAN, IMSL.	GIFTS STAGS STAR	SRDC NAST-RAN	SAP-IV	SAP-IV, NAST-RAN			•			EAL	GIFTS	ANSYS	HES COMP	NAST-RAN	•			POLO-FINITE KUSTA	NAST-RAN	•
4.	Computer Graphics																					
	Graphic Enhancement of Structural Concepts		•	•					•					•	•		•		•	•		
	In the Classroom		•	•		•			•				•	•					•	•		
	Outside the Classroom		•	•					•			•		•	•	•						
5.	Videotape Courses, TV Courses and Movies	•	•		•	•			•			•	•	•	•							•
6.	Industry Programs																					
	Co-op Program for Undergraduates	•	•		•	•		•			•		•	•	•		•			•	•	•
	Faculty Exchange Program with Industry		•						x					•						**		
	Tours of Industrial Facilities	•	•		•	•			•				•	•	•		•		•	•	•	
	Others	*		+		*+						•			+						**	

*Repetitive AIAA Speakers from Industry. **Joint Research with Industry. Speakers from Industry.
+Seminar Program.
x Starting

TABLE 3 (CONCLUDED)

PART IV - EDUCATIONAL AIDS

		U.S. Naval Academy	Boston University	Massachusetts Institute of Technology	Univ. of Michigan	Mississippi State Univ.	Parks College of St. Louis University	Univ. of Missouri	Rutgers University	Cornell University	New York Institute of Technology	Rensselaer Polytechnic Institute	State Univ. of New York at Buffalo	Air Force Institute of Technology	Ohio State University	Univ. of Cincinnati	Univ. of Oklahoma	Texas A&M University	Univ. of Texas at Austin	Univ. of Virginia	Virginia Poly. Inst. and St. Univ.
1.	Experimental Facilities and Models for Structures	•	•	•	•		•				•	•	•		•	•	•	•	•		
2.	Computer-Aided Instruction		•					•							•						
	Applying Microcomputers to Structures Education		•		•			•		•		•	•						•		
	Hands-on Experience		•		CALMA SYST.					•		•	•		•				•		
3.	Use of Large-Scale Computer Codes	GIFTS	SUPERB NAST-RAN, ANSYS		MSC/NAST-RAN		STRESS	++				•	•		NAST-RAN	•		NAST-RAN, ANSYS, ADINA	***	NAST-RAN ANSYS	
4.	Computer Graphics																				
	Graphic Enhancement of Structural Concepts		•									•	•		•						
	In the Classroom		•									•	•		•				•		
	Outside the Classroom		•							•			•				•		•	•	
5.	Videotape Courses, TV Courses and Movies		•		•								•	•					•	•	
6.	Industry Programs																				
	Co-op Program for Undergraduates			•	•		•	•			•	•	•		•	•	•	•	•		
	Faculty Exchange Program with Industry	•	•										•			•	•	•	•		
	Tours of Industrial Facilities	•	•				•	•			•	•	•		•		•	•	•	•	
	Others														*		+	+	**	•	

*Repetitive AIAA Speakers from Industry
**Joint Research with Industry. Speakers from Industry.
***NASTRAN, ANSYS, SAP, MODAL-PLUS.
+Seminar Program.
++NASTRAN, ADINA, ADINAT, SUPERTAB.

TABLE 4 - LIST OF VIDEOTAPE COURSES FROM AMCEE

Course Title	Instructor and University	Number of Hours	Number of Videocassettes	Fee		Comments
				Rental	Purchase	
I. MECHANICS OF DEFORMABLE SOLIDS						
1. Introduction to Stress Analysis	W. Riley L. Zachery Iowa State University		9	$850	$3250	Lecture notes - $8.95. Classroom without students.
2. Mechanics of Materials	W. Riley Iowa State University		41	$2750	$7500	Textbook, "Mechanics of Materials," 4th ed., Higdon, Ohlsen, Stiles, Weese & Riley; Macmillan Pub. Co., $38.95. Undergraduate level course. Classroom with students.
3. Mechanics of Composite Materials	R. F. Gibson University of Idaho	42	42	$2100 (6 months)	$8400	Textbook, "Mechanics of Composite Materials," R.M. Jones, McGraw-Hill, 1975, $45. Graduate level course. Classroom with students. Academic credit.
4. Advanced Mechanics of Materials	W. F. Riley Iowa State University	44	44	$2750	$7500	Textbook, "Mechanics of Materials," 4th ed., Higdon, Ohlsen, Stiles, Weese & Riley; Macmillan Pub. Co., $38.95. Graduate level course. Classroom with students.
5. Advanced Mechanics of Deformable Bodies	J. W. Phillips Univ. of Illinois at Urbana-Champaign	42	42	$2700	$11,000	Textbook, "Advanced Mechanics of Materials," 3rd ed., Boresi, Sidebottom, Seely & Smith, John Wiley & Sons. One set of course notes included with rental or purchase. Undergraduate/Graduate level course.
6. Theory of Elasticity with Application to Engineering Problems	K. S. Kim Univ. of Illinois at Urbana-Champaign	58	58	$3600	$12,000	Textbook, "Mathematical Theory of Elasticity," 2nd ed., I.S. Sokolnikoff, McGraw-Hill. Graduate level course. Classroom with students.
7. Elasticity.	Y. J. Chao Univ. of South Carolina	32½	39		$6000	Textbook, "Foundations of Solid Mechanics," Y.C. Fung, 1965.
8. Continuum Mechanics	W. F. Ranson Univ. of South Carolina	32½	39	$1500	$6000	Textbook, "Continuum Mechanics," Frederick & Chang, Scientific Pub., $25.75. Graduate level course. Classroom with students.

TABLE 4 (CONTINUED)

Course Title	Instructor and University	Number of Hours	Number of Videocassettes	Fee		Comments
				Rental	Purchase	
II. STRUCTURAL ANALYSIS AND STRUCTURAL STABILITY						
1. Structural Analysis	R. B. Pool Univ. of South Carolina	32½	39	$1500	$6000	Graduate level course. Classroom with students. Course notes. Prerequisite: A first course in structural analysis.
2. Structural Analysis II	J. H. Bradburn Univ. of South Carolina	32½	39	$1500	$6000	Textbook, "Structural Analysis," A. Chajes, Prentice-Hall, 1983. Prerequisite: A first course in structural analysis. Graduate level course. Classroom with students. Academic credit.
III. STRUCTURAL DYNAMICS						
1. Vibrations	C. Poli University of Massachusetts			$5400	$15,000	Textbook, "Elements of Vibration Analysis," L. Meirovitch, McGraw-Hill, 1975. Graduate level course. Classroom with students. Lecture notes.
2. Vibrations of Mechanical Systems I	R. L. Weaver Univ. of Illinois at Urbana-Champaign	43	43	$2700	$11,000	Textbook, "Elements of Vibration Analysis," L. Meirovitch, McGraw-Hill, 1975. Course notes included in rental or purchase. Graduate/undergraduate level course. Classroom with students.
3. Fundamentals of Dynamic Analysis for Structural Design - Earthquake and Wind Problems	R. B. Pool Univ. of South Carolina	12	12	$800	$2500	Course notes.
4. Dynamic Analysis	J. Dickerson Univ. of South Carolina	32½	39	$1500	$6000	Textbook, "Dynamics of Structures," R. Clough and J. Penzien, McGraw-Hill.
5. Advanced Dynamics	C. Poli University of Massachusetts	47	47	$5400	$15,000	Textbook, "Advanced Dynamics - Modeling and Analysis," A.F. D'Souze & V.K. Garg, Prentice-Hall, 1984. Lecture notes included. Graduate level course. Classroom with students.

TABLE 4 (CONTINUED)

Course Title	Instructor and University	Number of Hours	Number of Videocassettes	Fee		Comments
				Rental	Purchase	
IV. COMPUTATIONAL MECHANICS						
1. Numerical Analysis of Solids and Structures	H. D. Hibbitt consultant	6	6	$420	$1230	Lecture Notes. Classroom without students.
2. Applied Numerical Methods with Applications for Microcomputers	W. Hager University of Idaho	18	18	$935 (6 months)	$3635	Textbook, "Applied Numerical Methods," 3rd ed., Gerald & Wheatley, Addison-Wesley, 1984. Classroom with students. Prerequisite: Calculus, differential equations and minimal programming ability.
3. Parallel Processing	K. Hwang University of Southern California	35	56	$3000	$8800	Textbook. Graduate level course. Classroom with students. Prerequisite: Graduate computer architecture course or equivalent.
4. Introduction to the Finite Element Method	T. Rogge Iowa State University	42	42	$2750	$7500	Textbook, "Introduction to the Finite Element Method," Reddy, McGraw-Hill, $36. Undergraduate level course. Classroom with students.
5. Introduction to Finite Elements in Engineering	J. L. Turner Auburn University	28	28	$2800		Course notes and computer programs. Graduate level course. Academic credit. Classroom with students.
6. Finite Element Method and Its Development	O.C. Zienkiewicz University of Wales, U.K.	8	8	$560	$1640	Textbook, "The Finite Element Method," O.C. Zienkiewicz, McGraw-Hill, 1978, $25.95. Classroom without students.
7. Finite Element Methods in Engineering Mechanics	K. J. Bathe Massachusetts Institute of Technology		12 (55 min. ea)	$1595 (6 weeks)	$5340	Textbook, "Finite Element Procedures in Engineering Analysis," K.J. Bathe, Prentice-Hall, 1982, $41.95. Study Guide. Graduate level course. Prerequisite: Undergraduate degree in engineering or science.
V. DESIGN						
1. Stress-Strain-Strength Considerations in Design	R. C. Juvinall University of Michigan		39 (50 min. ea)	$3000	$10,900	Textbook, "Engineering Considerations of Stress, Strain and Strength," R.C. Juvinall, McGraw-Hill, 1967. Course notes. Graduate level course. Classroom with students.

TABLE 4 (CONTINUED)

Course Title	Instructor and University	Number of Hours	Number of Videocassettes	Fee		Comments
				Rental	Purchase	
VI. COMPUTER GRAPHICS AND CAD/CAM						
1. Introduction to Interactive Computer Graphics: A Concentrated Short Course	F. S. Hill, Jr. University of Massachusetts		13	$1625	$4810	Textbook, "Fundamentals of Interactive Computer Graphics," J. Foley & A. VanDam, Addison-Wesley, $39.95. Study Guide.
2. Introduction to Interactive Computer Graphics	F. S. Hill, Jr. University of Massachusetts		39	$5400	$15,000	Textbook, "Fundamentals of Interactive Computer Graphics," J. Foley & A. VanDam, Addison-Wesley, $39.95. Graduate level course. Classroom with students.
3. Advanced Computer Graphics and Computer-Aided Design	F. S. Hill, Jr. University of Massachusetts		42	$5400	$15,000	Textbooks, "Principles of Interactive Computer Graphics," Newman, Sproull, 2nd ed., McGraw Hill, 1979; and "Computational Geometry for Design and Manufacture," Faux, Pratt, Ellic, Horwood, John Wiley, 1979 Graduate level course. Classroom with students.
4. CAD/CAM Technology	J. A. Messina Northeastern University	22	22	$2000	$4500	Textbook, "CAD/CAM Computer Aided Design and Manufacture," Groorer, Prentice-Hall, $36.95. Classroom with students.
5. Introduction to Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM)	C. Zinsmeister University of Massachusetts		49	$5400	$15,000	Textbook, "CAD/CAM: Computer-Aided Design and Manufacturing," M.P. Groover & E. W. Zimmers, Prentice Hall, 1984. Graduate level course. Classroom with students.
VII. MATERIALS AND EXPERIMENTAL MECHANICS						
1. Composite Materials	A. A. Fahmy North Carolina State Univ.	30	25	$2600		Graduate level course. Classroom with students. Lecture notes. Lecture notes. Prerequisite: knowledge of mechanical properties of materials.
2. Fundamentals of Nondestructive Testing	C. J. Hellier consultant	10				Textbook, "ASM Metals Handbook, Nondestructive Testing and Quality Control," Vol. 11. Reading modules. Preview.

TABLE 4 (CONTINUED)

Course Title	Instructor and University	Number of Hours	Number of Videocassettes	Fee: Rental	Fee: Purchase	Comments
VII. MATERIALS AND EXPERIMENTAL MECHANICS (Cont'd.)						
3. Designing Experimentally with Photoelasticity	W. F. Swinson Auburn University	28	28	$2870		Graduate level course. Classroom with students. Academic credit. Course notes. Preview package.
VIII. ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS						
1. Introduction to Artificial Intelligence	M. N. Szilagyi Univ. of Arizona	12	12	$960 (12 weeks)	$3360	Classroom without students.
2. Artificial Intelligence	J. R. Siegel Northeastern University	20	20	$2000	$4500	Textbooks, "Artificial Intelligence," Rich, McGraw-Hill, $33; and "Handbook Vol. I of Artificial Intelligence," Barr, Kaufman, $39.50. Classroom with students.
3. Artificial Intelligence - Concepts and Language	A. Blue North Carolina State Univ.	30	25	$2600		Textbooks, "Artificial Intelligence," 2nd ed., Winston, Addison-Wesley; and "L/Sp," 2nd ed., Winston & Horn, Addison-Wesley. Lecture notes. Graduate level course. Classroom with students.
4. Artificial Intelligence in Manufacturing	E. L. Fisher North Carolina State Univ.	40	27	$2600		Textbook, "Designing Intelligent Systems," I. Alexander, 1984. Graduate level course. Classroom with students. Prerequisite: some knowledge of expert systems and knowledge engineering.
5. Advanced Topics in Artificial Intelligence	P. R. Cohen Univ. of Massachusetts	36	47	$5400	$15,000	Textbooks, "The Handbook of Artificial Intelligence," Vols. I, II & III, Barr, Cohen and Feigenbaum, W. Kaufmann, Inc., 1982; and "A Practical Guide to Designing Expert Systems," Weiss & Kulikowski, Rowman and Allanheld, 1984. Graduate level course. Classroom with students.
6. Expert Systems	W. Ahmed Univ. of Southern California	32	39	$3000	$8800	Textbook, "Programming in Prolog," Clocksin & Mellish, Springer-Verlag. Graduate level course. Classroom with students. Prerequisite: Graduate courses in artificial intelligence and machine perception.

TABLE 4 (CONCLUDED)

Course Title	Instructor and University	Number of Hours	Number of Videocassettes	Fee		Comments
				Rental	Purchase	
VIII. ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS (Cont'd.)						
7. Expert Systems and Knowledge Engineering	W. J. Rasdorf E. L. Fisher North Carolina State Univ.		25	$2600		Textbook, "Building Expert Systems," Hayes-Roth, Waterman and Lenat, Addison-Wesley. Graduate level course. Classroom with students. Lecture notes.

TABLE 5 - LIST OF PARTICIPATING UNIVERSITIES, NASA CENTERS AND PROJECTS FOR THE ADVANCED DESIGN PROGRAM

University	NASA Center	Project
	a) Advanced Aeronautics Design	
1. University of California at Los Angeles 2. California Polytechnic State University	Ames Research Center	● Aerospace Plane Computer Vision Controls ● VTOL Aircraft Concepts
3. University of Kansas 4. Purdue University	Langley Research Center	● Family of Advanced Facility for the Space Station ● 200 Passenger Transport 115 Passenger Transport Flying Wing Military Transport Assault Transport (5 Person Team) Assault Transport (6 Person Team)
5. Case Western Reserve University 6. Ohio State University	Lewis Research Center	● Hypersonic Transport Aircraft ● Hypersonic Trans-Pacific Flight
	b) Advanced Space Design	
1. University of Colorado 2. University of Wisconsin	Ames Research Center	● Long Term Space Habitat ● Rover Design for a Mars Sample Return Mission Design of a CO2 Engine Structural Design of a Mars Habitat Development of a Spacesuit Glove Development of a Portable Oxygen Production Unit

TABLE 5 (CONTINUED)

University	NASA Center	Project
3. U.S. Naval Academy	Goddard Space Flight Center	• Variable Artificial Gravity Facility for the Space Station
4. University of Maryland	Goddard Space Flight Center	• Space Station Automation and Robotics
5. California Institute of Technology	Jet Propulsion Lab.	• Design of a Mars Rover
6. Utah State University	Jet Propulsion Lab.	• The Mars Lander/Rover (MLR)
7. University of Texas	Johnson Space Center	• Phobos Base for Mars Exploration
8. University of North Dakota	Johnson Space Center	• Variable Gravity Research Facility
9. Prairie View A&M University	Johnson Space Center	• Design of Surface Based Factory for the Production of Life-Support and Technology-Support Products
10. Clemson University	Johnson Space Center	• Production of a Fiber Glass Metal Composite Material Suitable for Building Habitat and Manufacturing Facilities
11. Worcester Polytechnic Institute	Johnson Space Center	• Ultrasonics and Space Instrumentation
12. Texas A&M University	Johnson Space Center	• Power and Propulsion System for a Deep-Space Scientific Probe
13. Old Dominion University	Johnson Space Center	• Mars Oxygen Processor Demonstration Unit
14. Florida Institute of Technology	Johnson Space Center	• Lunar Launch and Landing Facilities and Operations

TABLE 5 (CONCLUDED)

University	NASA Center	Project
15. Georgia Institute of Technology		• Construction Equipment for Lunar Base
16. University of Florida	Kennedy Space Center	• Bioregenerative System
17. Tuskegee Institute		• Lunox Storage and Transfer System
18. Virginia Polytechnic Institute Institute and State University	Langley Research Center	• Advance Transfer Vehicle with Aerobraking at Earth and Mars
19. Massachusetts Institute of Technology		• Mixed Fleet Earth Launch System ... or Space Station Design
20. University of Michigan	Lewis Research Center	• Personnel Transportation System Between Earth and Mars
21. University of Washington		• Multimegawatt Power System
22. University of Illinois	Marshall Space Flight Center	• Comet Explorer Spacecraft
23. Auburn University		• Two-Stage Launch Vehicle

TABLE 6 - UNIVERSITY CENTERS FOR COMMERCIAL DEVELOPMENT OF SPACE (CCDS)

Technology Focus	Center Management	University Affiliates	Industrial and Other Affiliates
1. "Generic" materials processing	Battelle Columbus Labs. Columbus, OH	Univ. of Akron Case Western Reserve Univ. Clarkson Univ. Cleveland State Univ. Ohio State Univ. Washington State Univ.	AMOCO Chemicals Corp. Celanese Corp. Eastman Kodak Co. Foster Wheeler Dev. Corp. General Electric Corp. Hercules, Inc. Lockheed MSC, Inc. PPG Industries, Inc. Rockwell International Rohm and Haas Co.
2. Macromolecular crystallography - Technology and applications for space-based material processing of biological crystals	Univ. of Alabama at Birmingham		McDonnell Douglas Astro. Merck Inst. for Therapeutic Research The Upjohn Co. Smith Kline & French Labs. Schering Corp.
3. Remote sensing technology	The Institute for Technology Development Jackson, MS	Jackson State Univ. Michigan State Univ. Mississippi State Univ. Univ. of Missouri Murray State Univ. Texas A&M Univ. Univ. of New Mexico Oklahoma State Univ. Pennsylvania State Univ. Univ. of California Univ. of Delaware Univ. of Kansas	EOSAT Synercom Hutson Chemical Geospectra Ducks Unlimited Industries Dev. Res. Council, Inc. DESTEK Mead Paper Co. Business In-Kind
4. Materials processing research with emphasis on crystals grown for optical applications	University of Alabama in Huntsville	Univ. of Alabama in Tuscaloosa	Boeing Aerospace Co. Celanese Research Co. Deere and Co. GTE Labs, Inc.

TABLE 6 (CONTINUED)

Technology Focus	Center Management	University Affilitates	Industrial and Other Affilitates
4. Materials processing (Cont'd.)			Martin Marietta Aerospace McDonnell Douglas Corp. Teledyne Brown Engineering Union Carbide Corp. Wyle Labs
5. Space processing of engineering materials with emphasis on aluminum casting and slip casting	Vanderbilt University Nashville, TN	Univ. of Alabama in Tuscaloosa Univ. of Florida in Gainesville	Oak Ridge National Lab. ALCOA ARMCO, Inc. Boeing Aerospace Co. Cabot Corp. Engelhard Corp. General Electric Corp. General Motors (Anderson, IN and Warren, MI) GTE Lockheed Missiles & Space Special Metals Co. Teledyne Brown Engineering Teledyne Wah Chang
6. Molecular beam epitaxy (MBE) development	Univ. of Houston University Park	Univ. of Illinois at Urbana-Champaign	Rockwell International AT&T Bell Labs Perkin-Elmer Corp. Wyle Labs. U.S. Army
7. Real-time satellite mapping	Ohio State University	Ohio Central State Univ. Stanford University Univ. of Michigan	Applied Information Technologies Research Center Battelle Columbus & Northwest Compuserve Destek Gas Research Institute General Electric Space Systems, Inc.

TABLE 6 (CONTINUED)

Technology Focus	Center Management	University Affilitates	Industrial and Other Affiliates
7. Real-time satellite (Cont'd.)			Intern. Imaging Systems OH Farm Bureau Federation Synercom, Inc. R.W. Teater & Assoc. Ohio Dept. of Development Ohio Dept. of Natural Resources Ohio Cooperative Ext. Ser.
8. Crystal growth in space	Clarkson University	Alabama A&M Univ. Univ. of Florida Rensselaer Polytechnic Institute Worchester Polytechnic Institute	New York State Barnes Engineering Boeing Electronics Grumman Corp. Rockwell Science Center Spectron Dev Labs Trans-Temp Quantum Technologies Brookhaven Nat. Lab. (AUI) DANTEC Electronics EG&G Bell Aerospace Textron TAM Ceramics, Inc. AVX Corp. OHMTEK, Inc. Westinghouse Crystal Specialties, Inc. CM Furnaces, Inc. Honeywell Science & Tech. Ethyl Corp. Honeywell EOD Sperry Corp. MA Ctrs of Excellence Corp.

TABLE 6 (CONCLUDED)

Technology Focus	Center Management	University Affiliates	Industrial and Other Affilitates
9. Space automation and robotics	University of Wisconsin at Madison	Marquette Univ. Univ. of Milwaukee Univ. of Wisconsin at Milwaukee	Astronautics Corp. of America Automated Systems Delco Johnson Controls, Inc. Madison Kipp Corp. Phyto Farms of America Pierson Products, Inc. Silicon Sensors Snap on Tools Corp. Sundstrand Corp. Dept. of Energy - Oak Ridge National Labs. State of Wisconsin

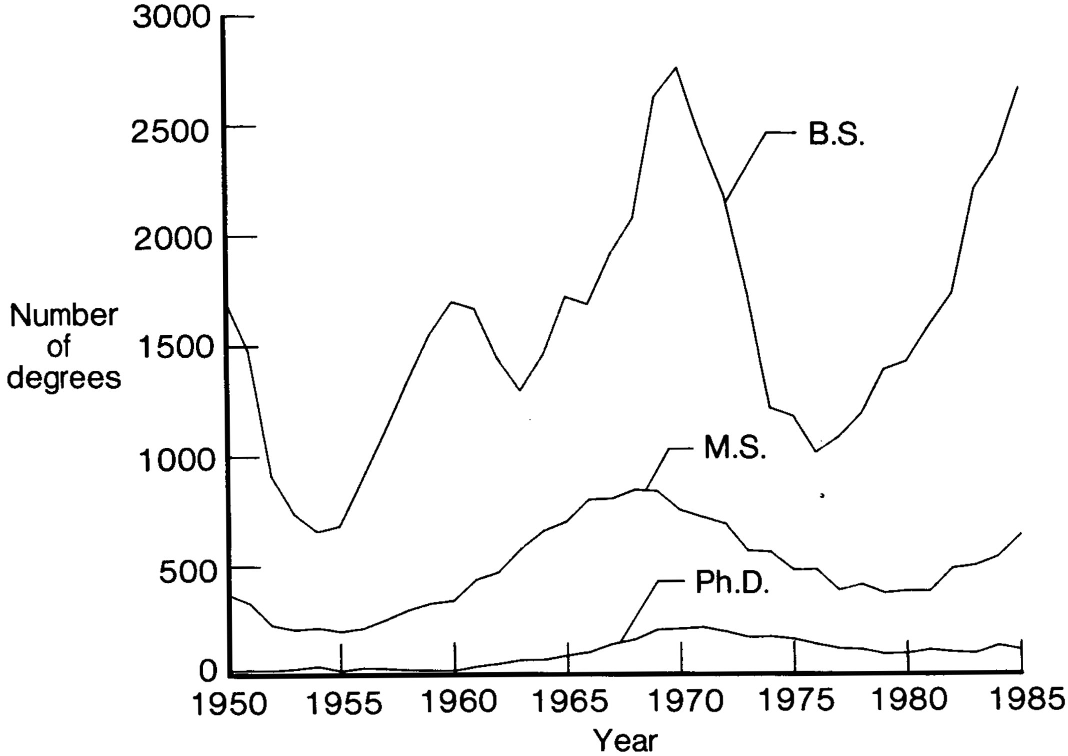

Figure 1 - Aerospace engineering degrees awarded by U.S. institutions from 1950 to 1985

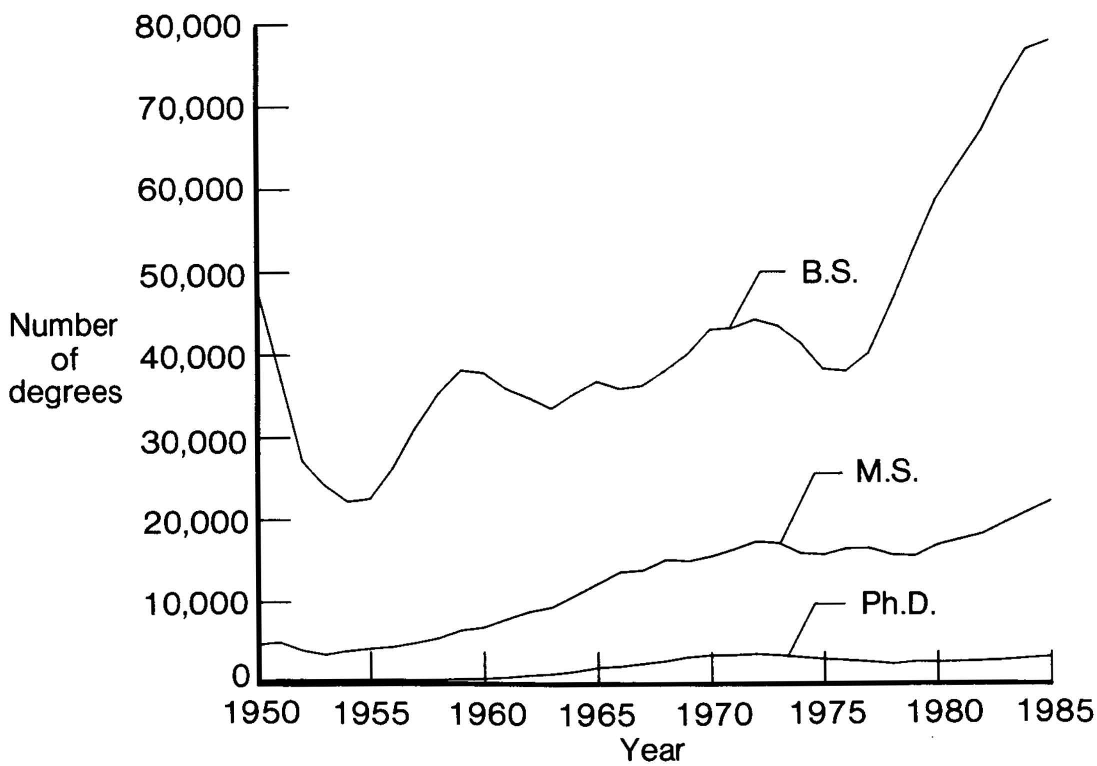

Figure 2 - Total engineering degrees awarded by U.S. institutions from 1950 to 1985

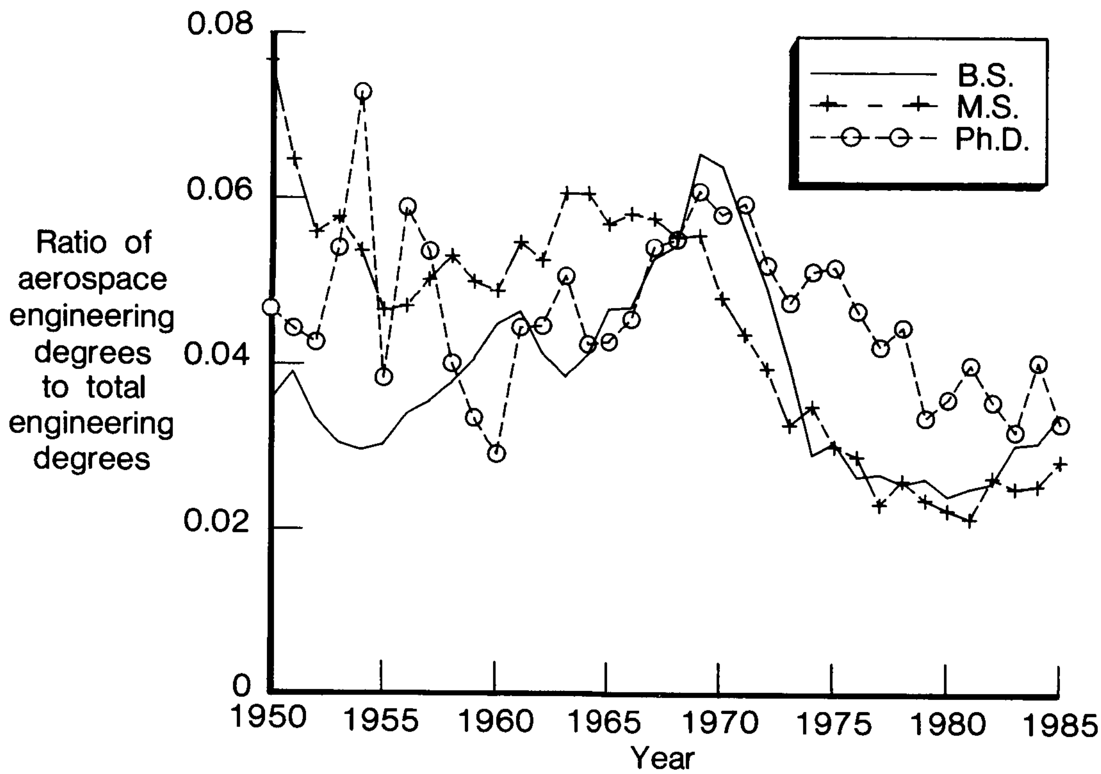

Figure 3 - Ratio of aerospace engineering degrees to total engineering degrees

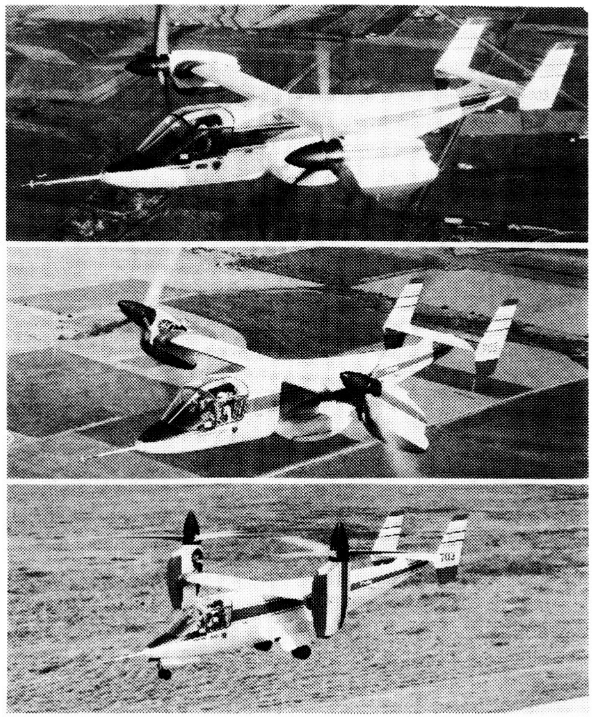

Figure 4 - XV-15 tilt rotor research aircraft with VTOL and STOL capabilities. It retains the vertical flight and hover advantages of a helicopter while being capable of efficient, smooth forward flight at speeds approaching those of current propeller driven airplanes.

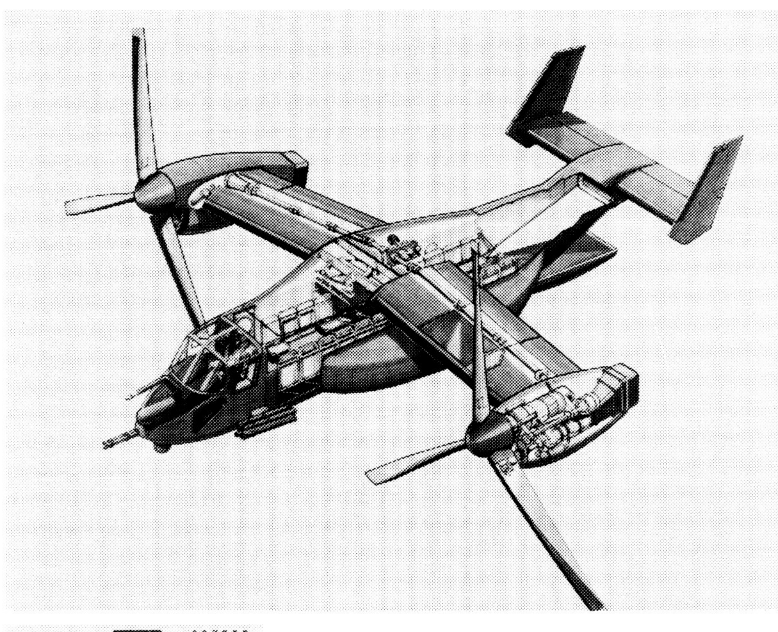

Figure 5 - Cutaway of V22 multimission tilt rotor aircraft (Boeing Vertol Company and Bell Helicopter Textron)

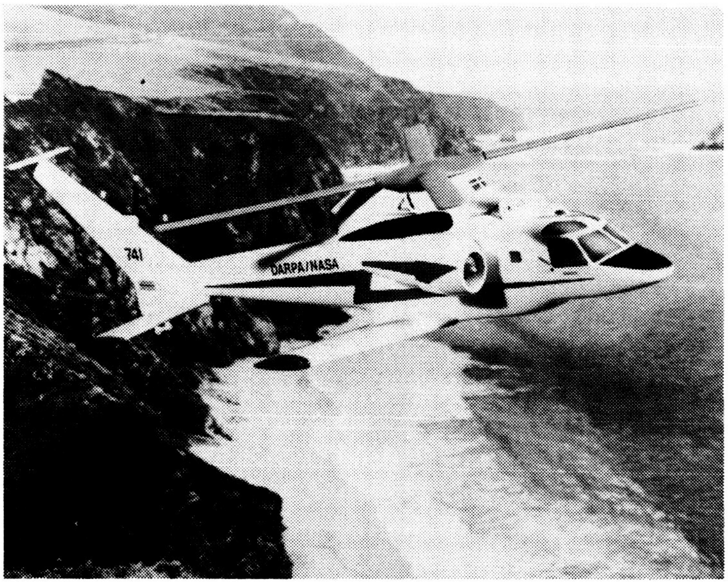

Figure 6 - DARPA/NASA/Sikorsky X-Wing concept has the vertical lift capability of helicopters while providing the range and speed abilities of fixed-wing aircraft. The X-Wing blades are made of graphite-epoxy composites and have a series of slots along their edges. Compressed air is blasted out of the slots to generate lift.

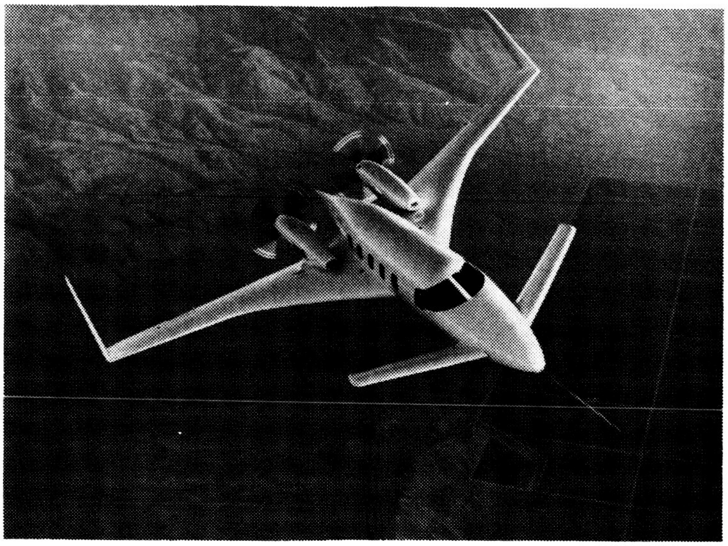

Figure 7 - Beechcraft Jetfan Starship 1 has tandem-wing design with variable geometry forward wing, twin pusher-propfan turbine engines. The jetfan is a convergence of jetprop, propfan and fanjet technology.

Figure 8 - Fuel-saving propfan mounted on the left wing of a Gulfstream II corporate jet (Lockheed-Georgia Company under contract to NASA Lewis Advanced Turboprop (ATP) Program).

Figure 9 - 1990's advanced commercial airliner with advanced propfan, lightweight composite and lithium-aluminum alloys (Boeing).

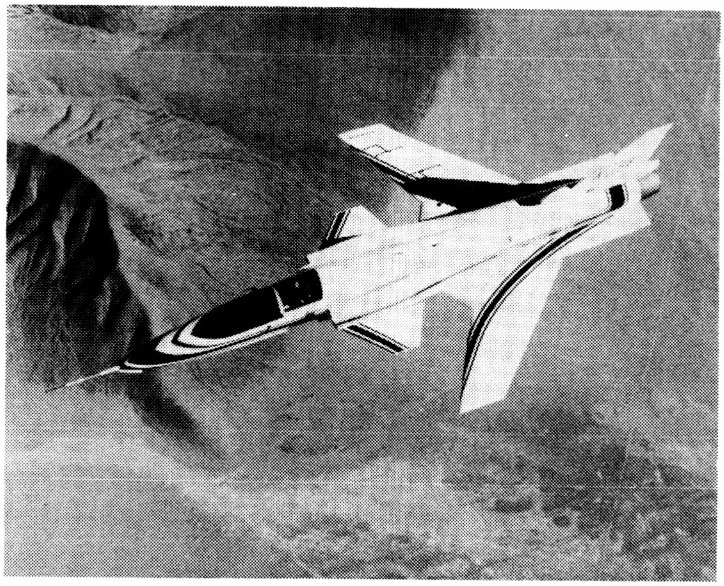

Figure 10 - X-29A advanced technology demonstrator - forward swept wing with advanced structures, aerodynamics and flight control technologies (Grumman/DARPA).

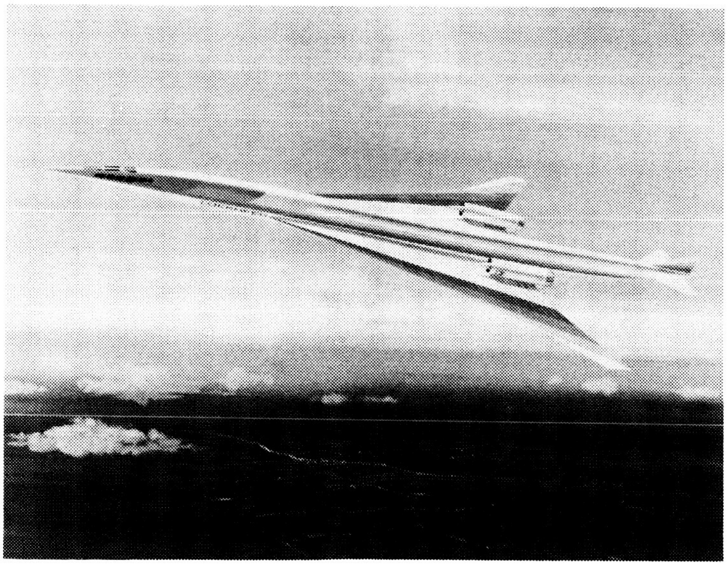

Figure 11 - Advanced supersonic transport (Mach 2.55) - (Lockheed California/NASA). Key technology opportunities include supersonic laminar flow, high-temperature variable cycle engines, and lightweight hot structures.

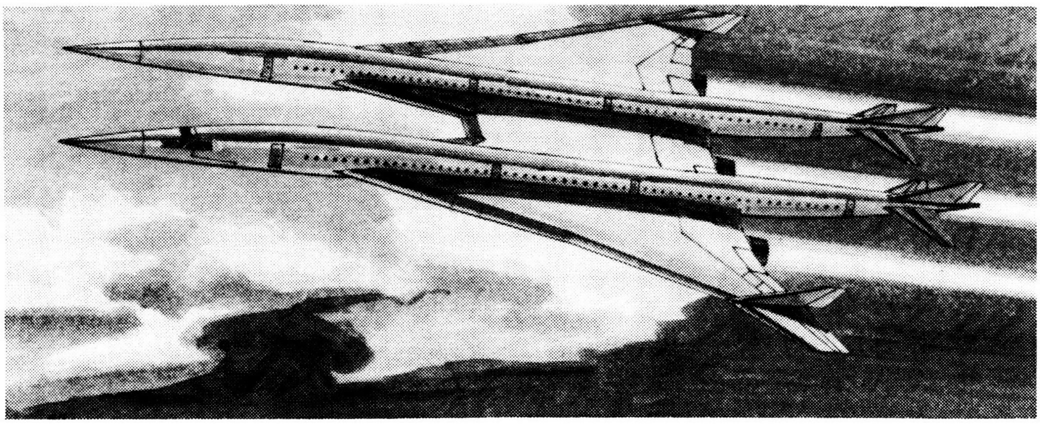

Figure 12 - Twin fuselage supersonic cruise transport concept provides higher aerodynamic and structural efficiencies.

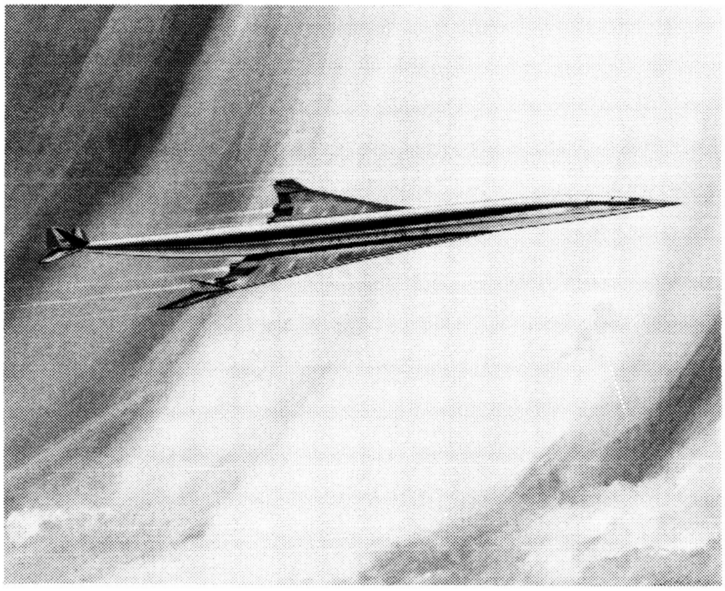

Figure 13 - Commercial jet transport powered by liquid hydrogen fuel for twenty-first century travel (Lockheed California Company).

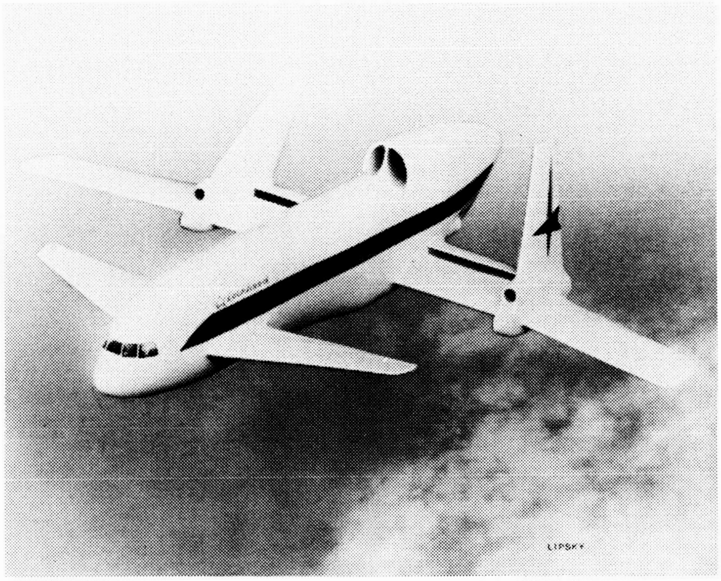

Figure 14 - Omega - twenty-first century airlifter (with fly-by-wire control system, composite airframe, electronic cockpit, and smooth aerodynamic coatings).

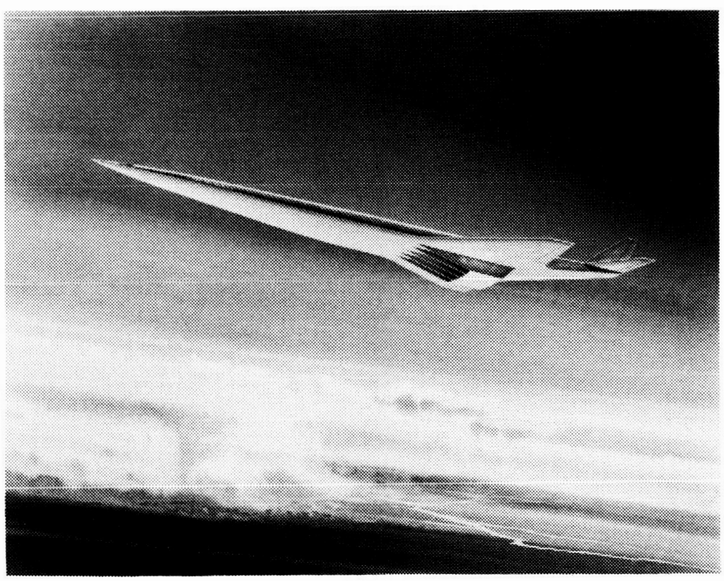

Figure 15 - Hypersonic passenger airliner (Lockheed/NASA) cruising speed 4000 mph, has propulsion system with both conventional turbojet engines and supersonic combustion ram (SCRAM) jet engines fueled by liquid hydrogen.

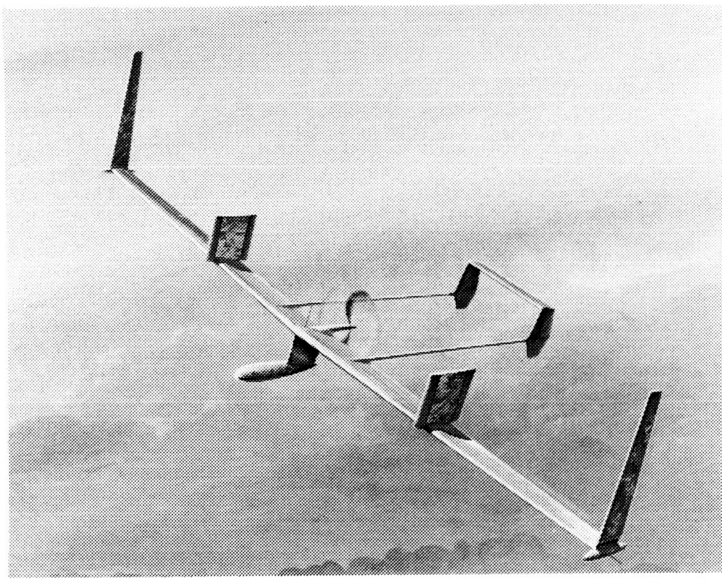

Figure 16 - Extremely high altitude aircraft - solar-powered example.

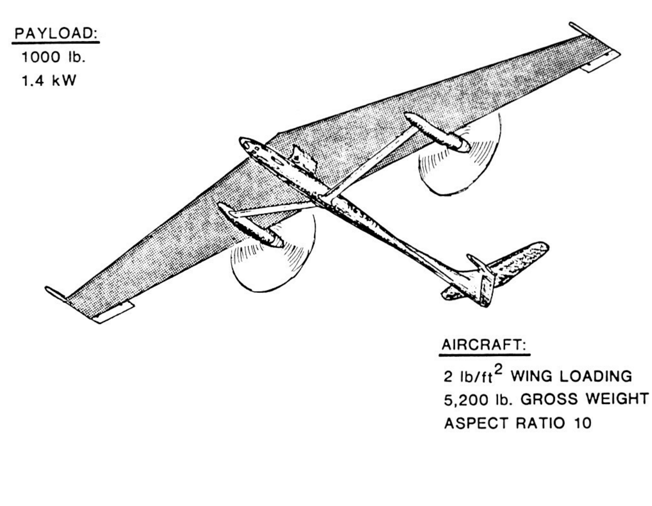

Figure 17 - Extremely high altitude aircraft - microwave powered example.

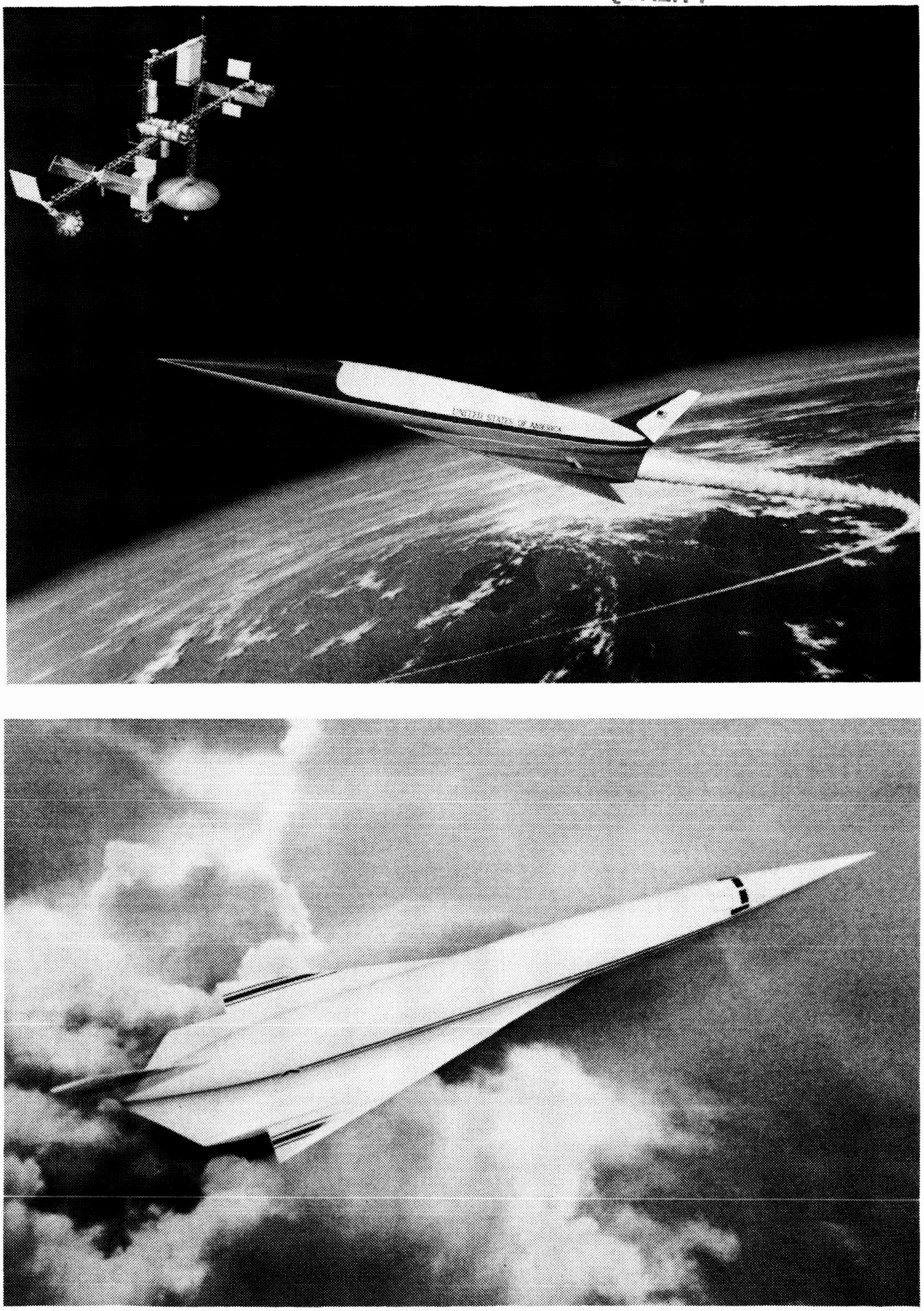

Figure 18 - Artist's conception of the National Aerospace Plane (NASP). Both an aircraft and a spacecraft - will be capable of taking off from and landing horizontally on conventional runways; sustaining hypersonic cruise in the atmosphere (at Mach 8 to 25 between altitudes 100,000 and 350,000 feet).

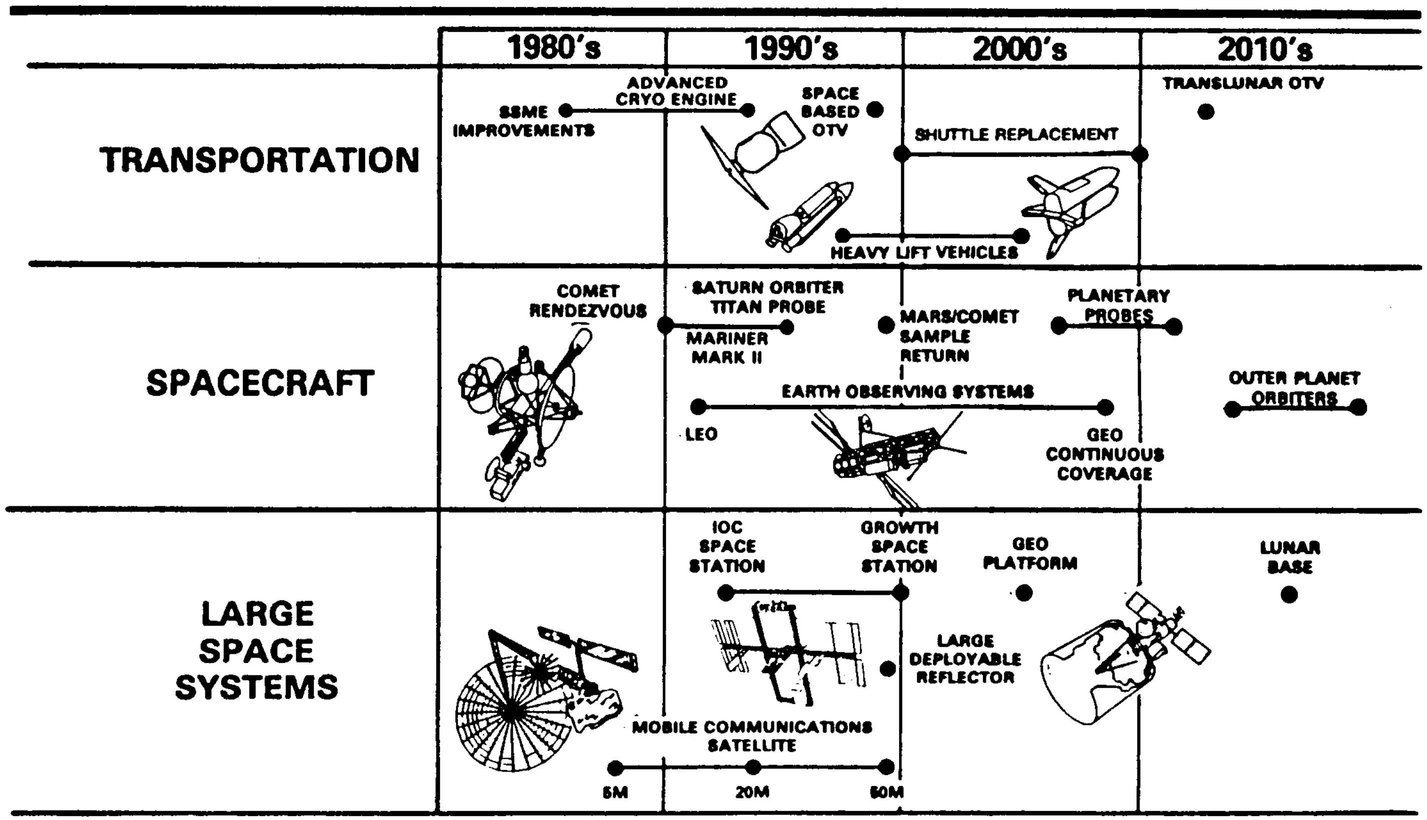

Figure 19 - Driver missions for space technology focus.

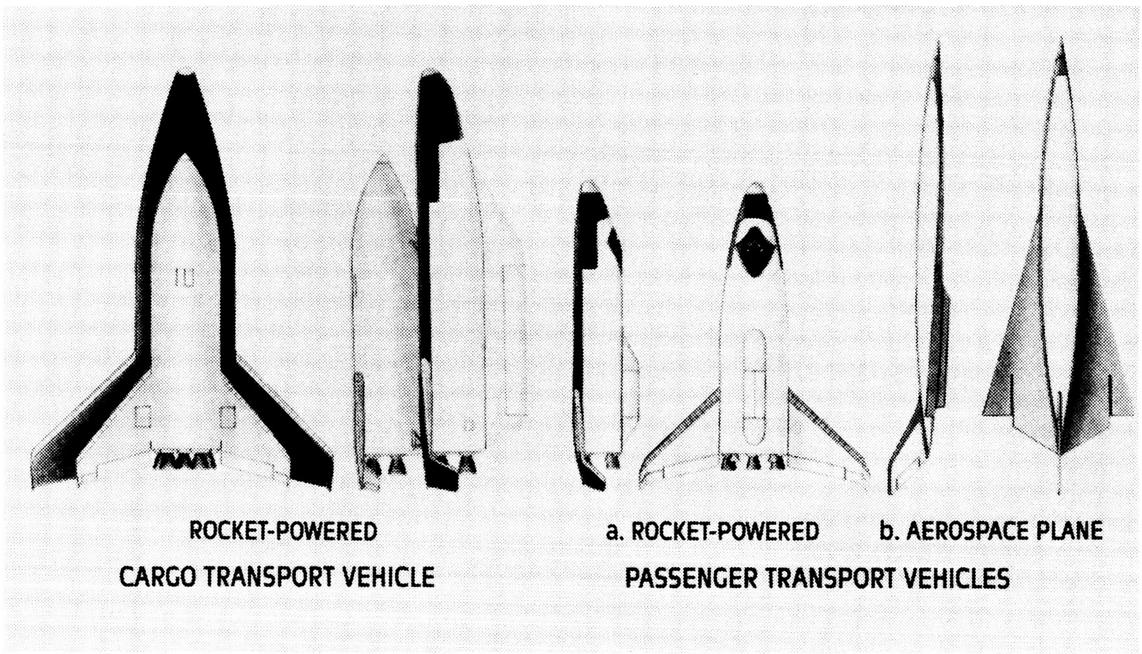

Figure 20 - Transport vehicle concepts (see Ref. 1).

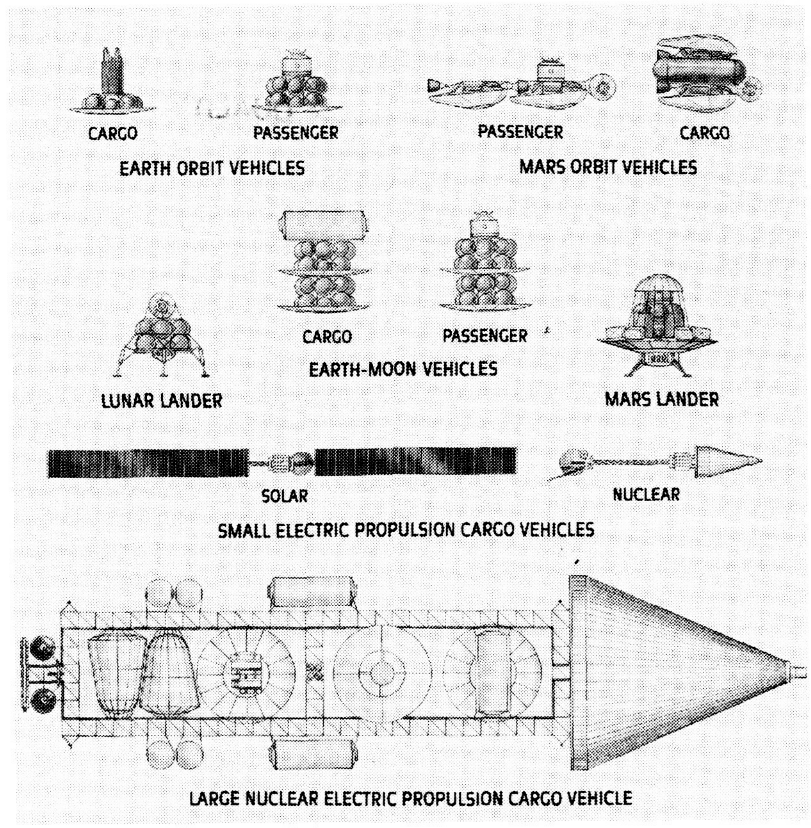

Figure 21 - Transfer vehicle concepts (see Ref. 1).

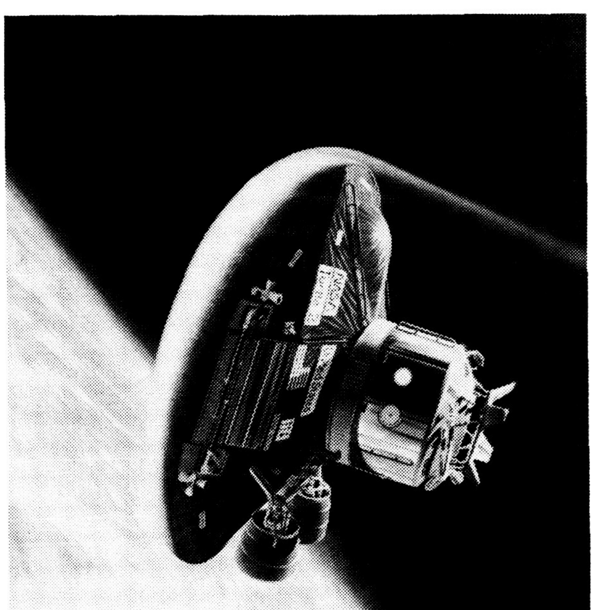

Figure 22 - Orbital transfer vehicle (OTV) concept permanently based at the planned space station and capable of retrieving satellites from GEO (22,300 miles high).

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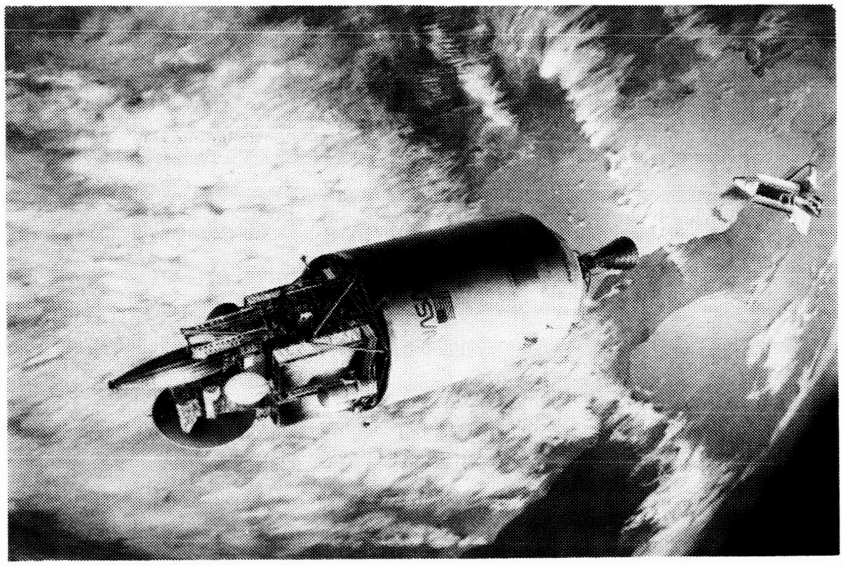


Figure 23 - OTV with a super COMSTAT (Boeing Aerospace/Marshall).

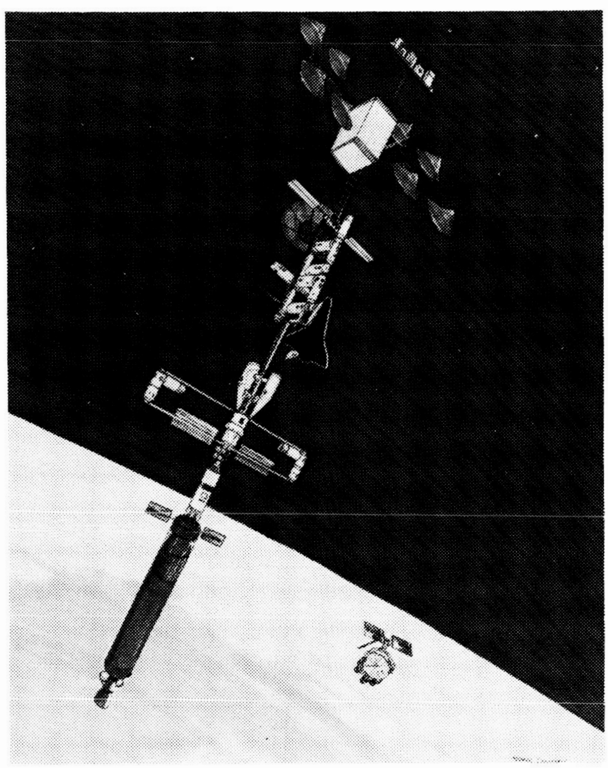


Figure 24 - Mars transfer vehicle in low earth orbit (JSC).

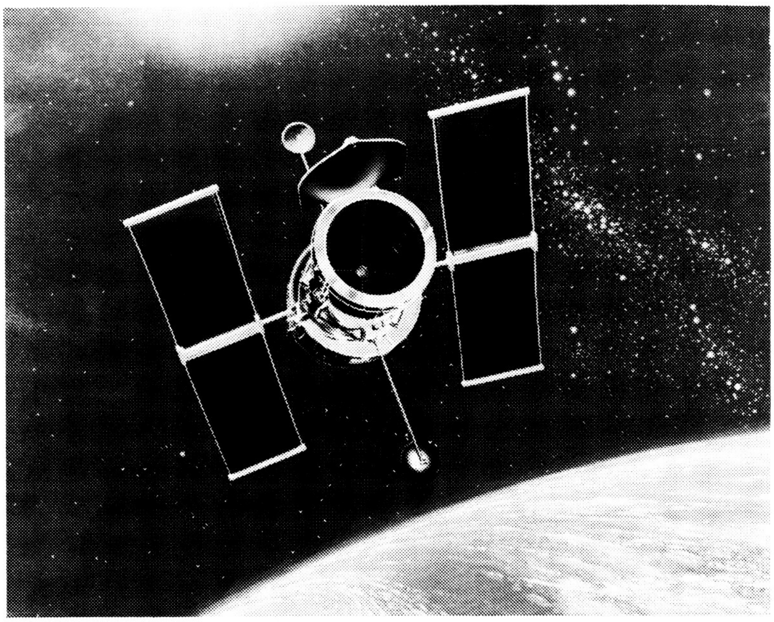


Figure 25 - Hubble Space Telescope has a two-camera system and will provide both extraordinarily detailed images of individual objects and wider field survey for object detection. Targets will range from planets, comets, and asteroids in the solar system to galaxies and quasars in deepest space.

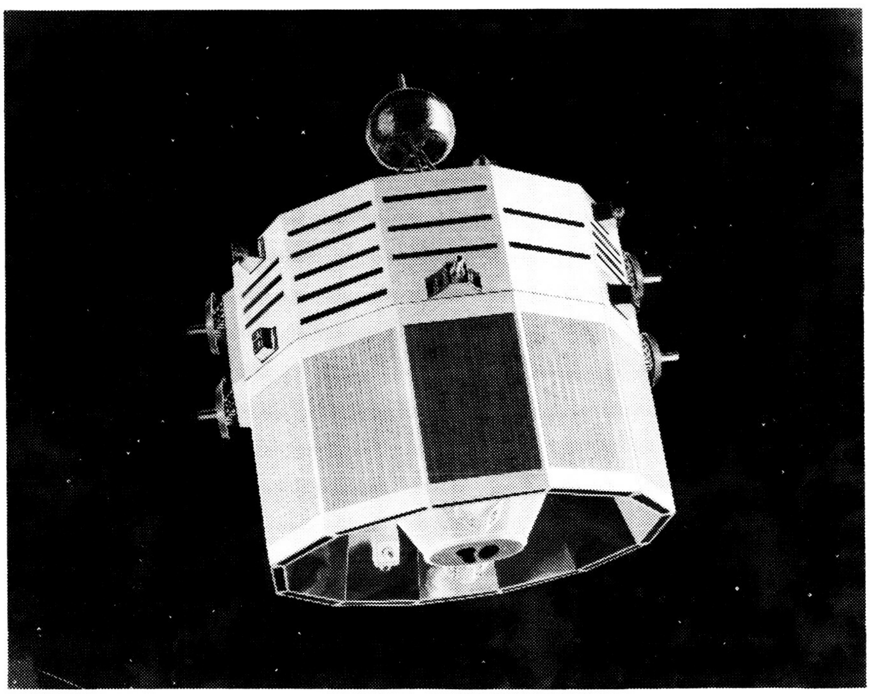


Figure 26 - Cosmic background explorer (COBE) will measure precisely the spectral and directional distribution of cosmic microwave background radiation.

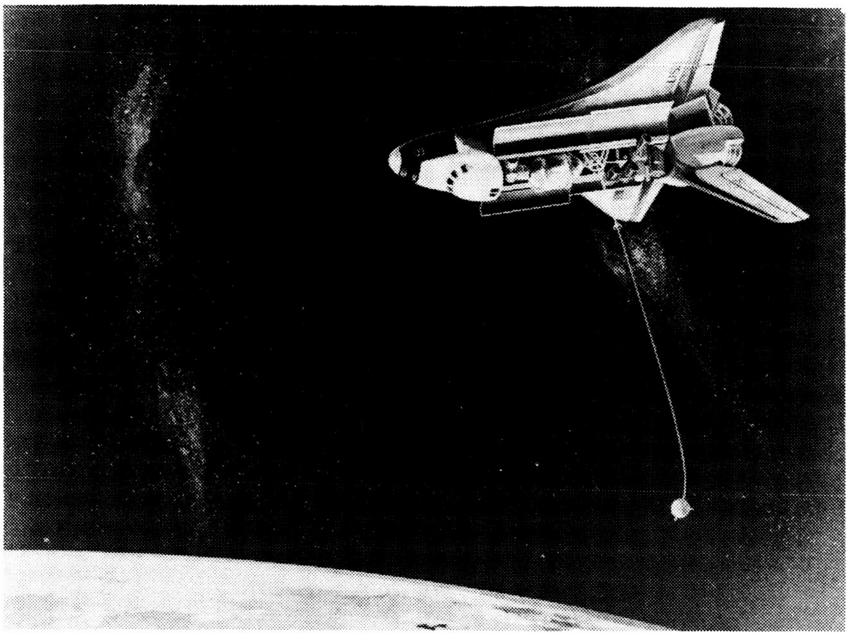


Figure 27 - Artist's concept of the tethered satellite system. The satellite is to be suspended from the cargo bay of the shuttle on a tether (superstrong polyethylene cord only two millimeters thick, but 60 miles long). The satellite will gather atmospheric, magnetospheric and gravity data from the upper atmosphere (50 to 90 miles up).

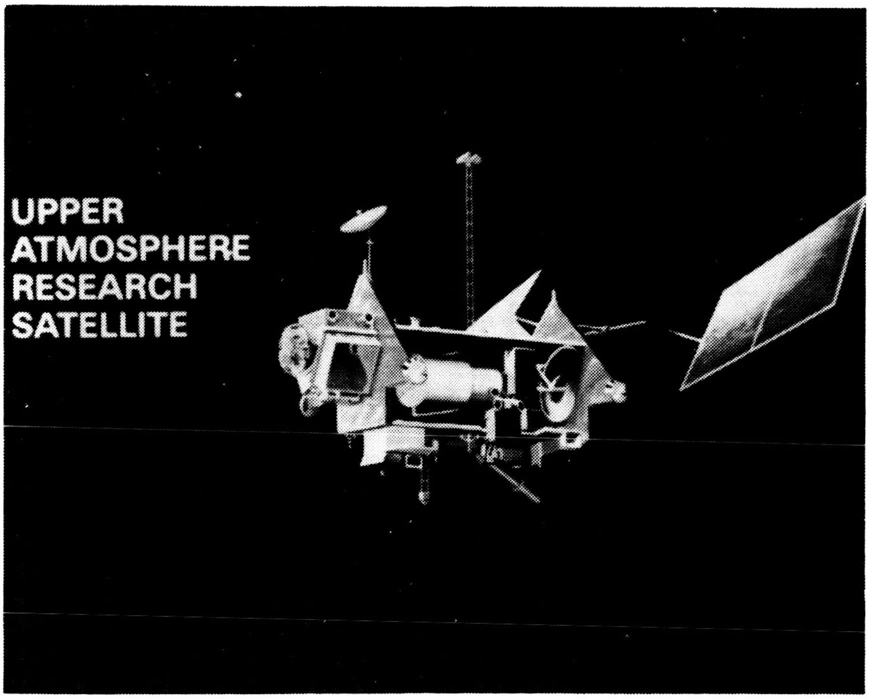


Figure 28 - Upper atmosphere research satellite.

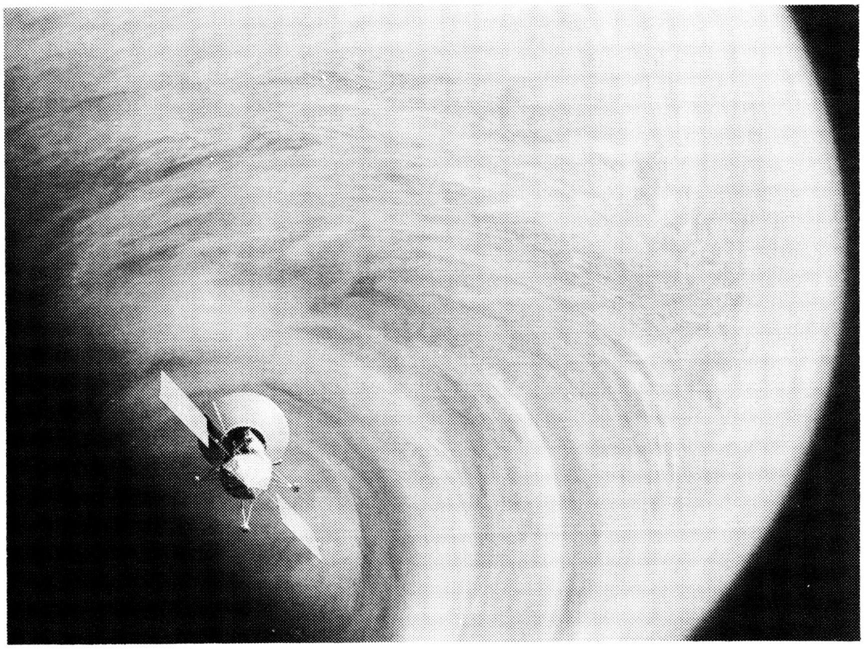


Figure 29 - Artist's depiction of Venus Radar Mapper (VRM) spacecraft as it orbits the cloud covered planet. The spacecraft has a synthetic aperture radar capable of performing both surface imaging and altitude measurement. The radar will be able to resolve surface features measuring less than one kilometer in size through the thick cloud layer that always covers Venus.

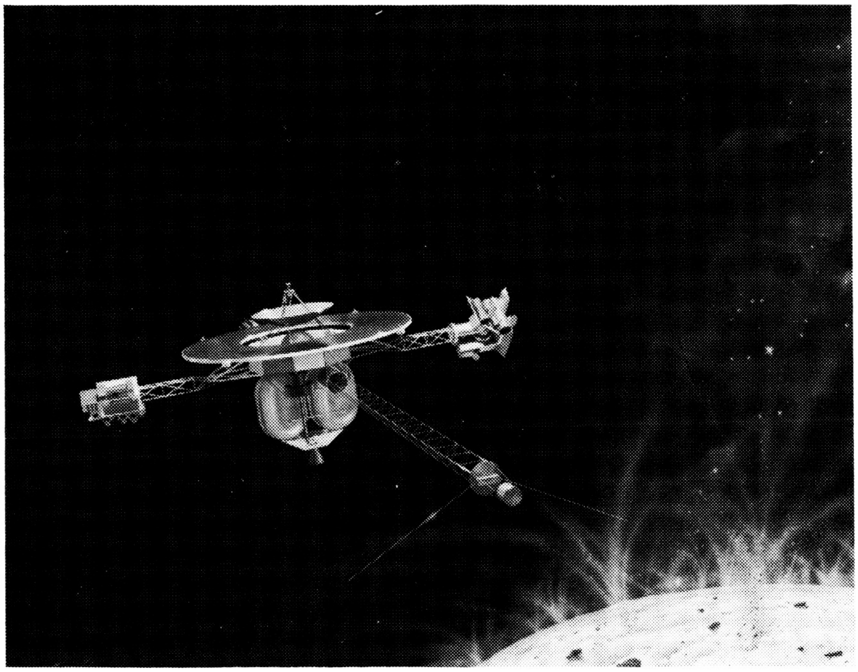


Figure 30 - Artist's rendition of Mariner Mark II - Comet rendevous/astroid flyby (CRAF), Proposed launch - March 3, 1991, to arrive at Comet Wild 2 near the orbit of Jupiter January 8, 1995 (JPL).

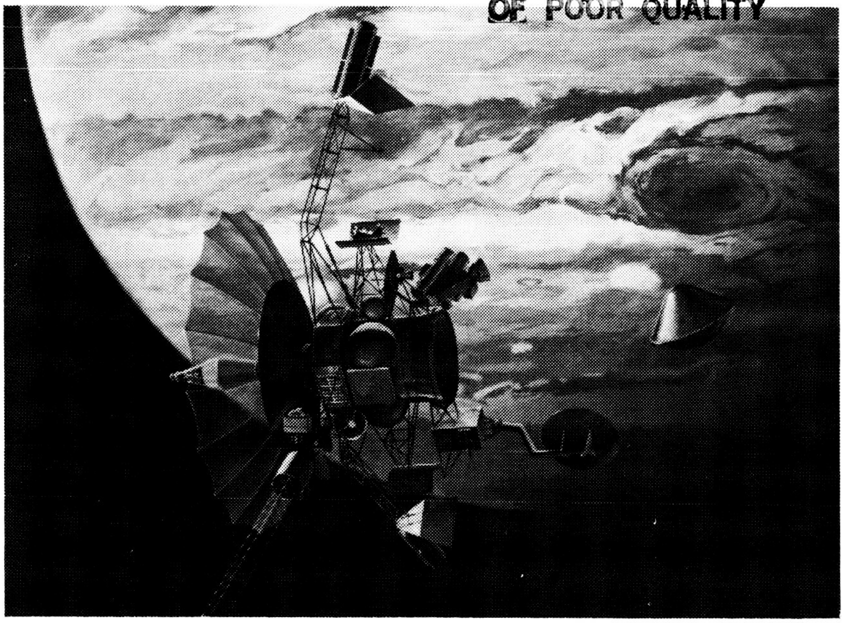


Figure 31 - Galileo orbiter and probe (cone-shaped probe, and orbiter dominated by the 16-foot-diameter high-gain communications antenna).

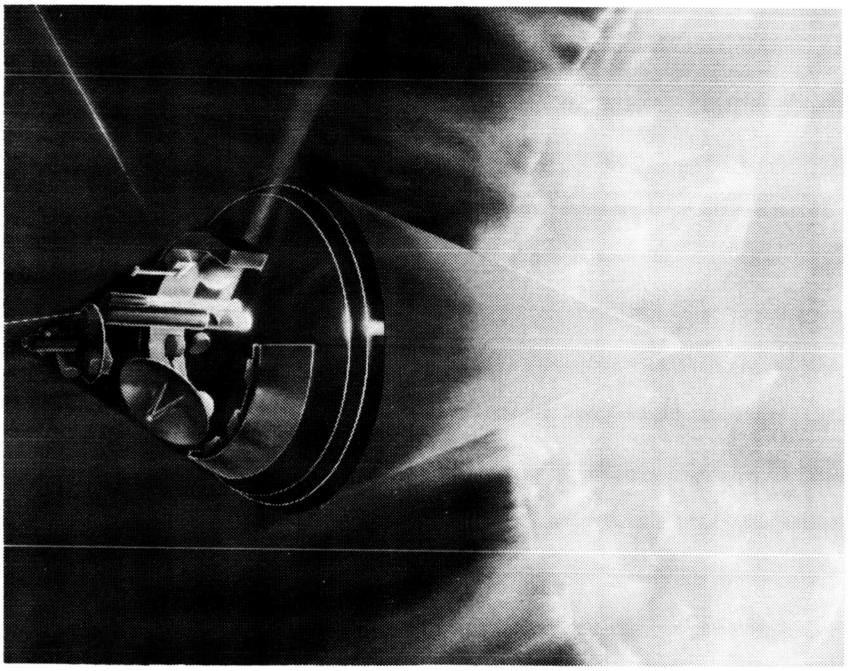


Figure 32 - Artist's impression of Starprobe approaching the sun. The spacecraft will fly to within four radii of the sun's surface to observe the sun's surface, gravitational figure, and upper atmosphere. The three areas of new technology are: a) heat shield; b) communication system; and c) drag compensation system.

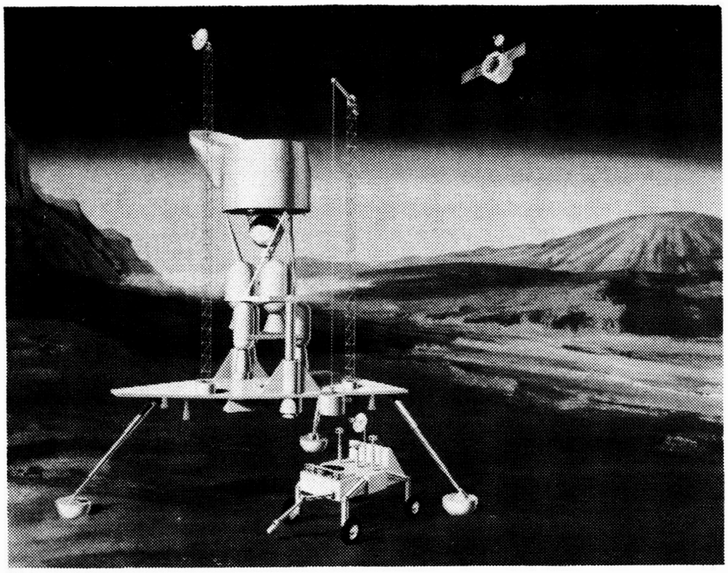
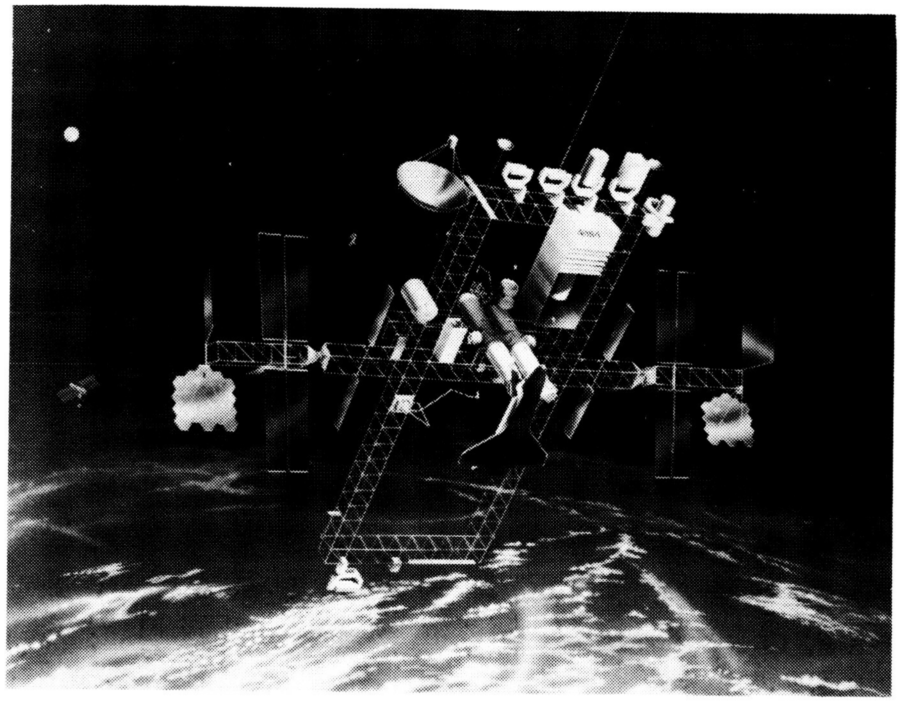


Figure 33 - Artist's impression in three segments. Mars sample return mission consisting of four-wheeled robotic rover, ascent vehicle and orbiter (JPL - proposed for 1996 launch). Sample being transferred from rover to the sample - return canister.



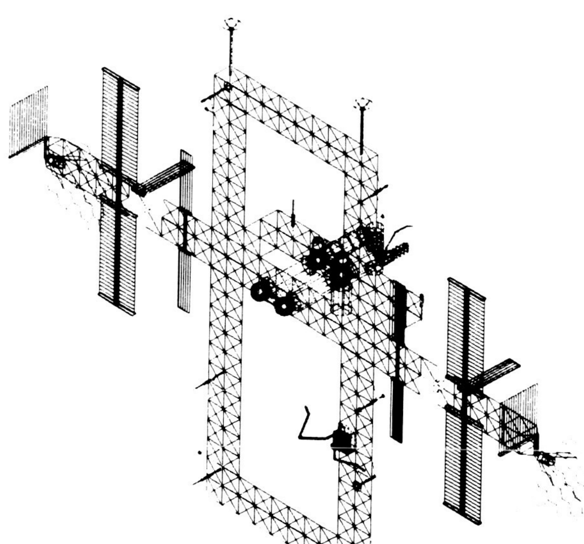


Figure 34 - Space Station.

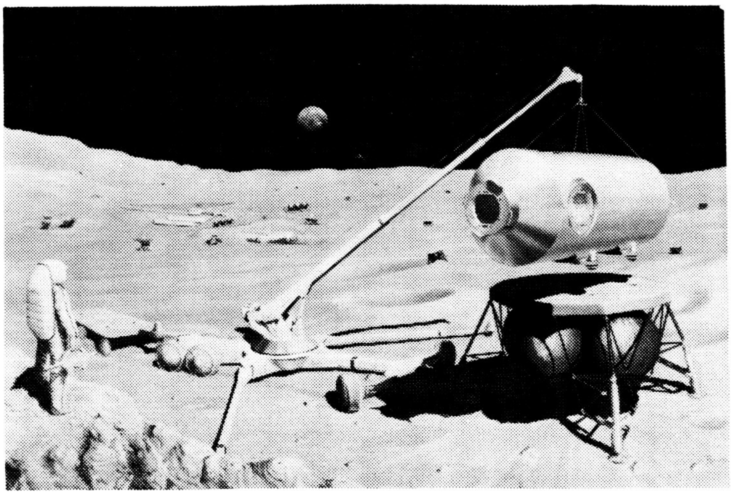


Figure 35 - Early stages of a moon base consisting of buried habitat modules (seen from a distance); thermal radiators for a nuclear power complex (inverted cones); mobile crane removing a common module from the descent stage (NASA/JSC).

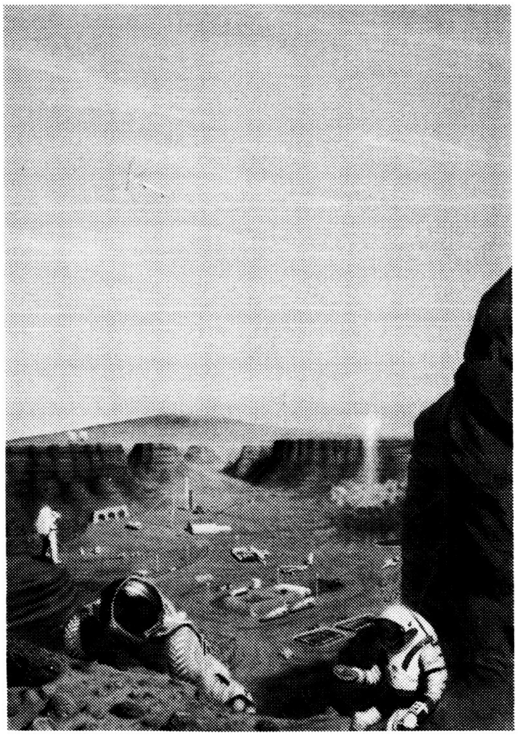


Figure 36 - Mars base including traverse vehicle; greenhouses, central base, launch and landing areas; water well pumping station, tunneling device (JSC).

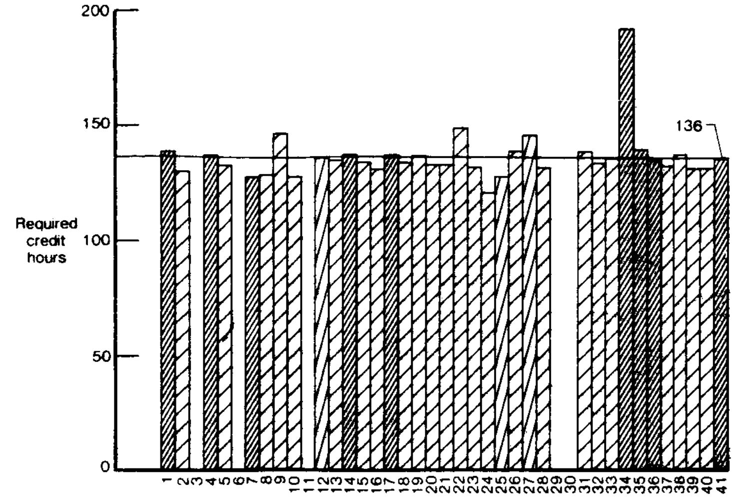


Figure 37 - Total number of credit hours required for B.S. degree.

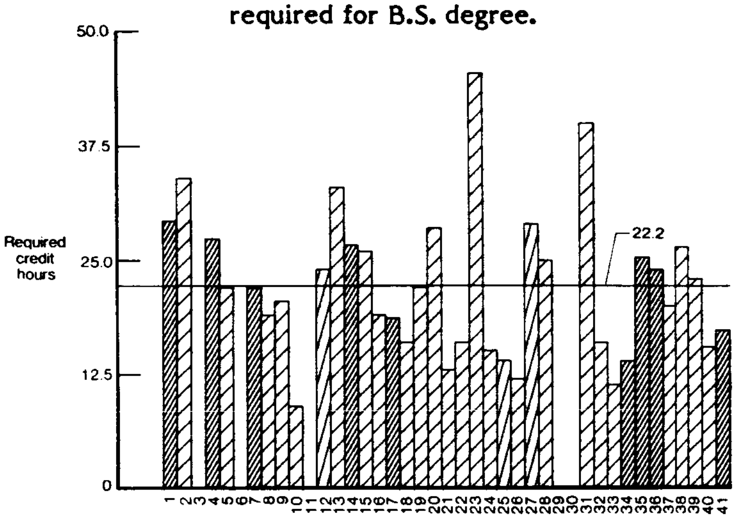


Figure 38 - Total number of required credit hours in flight-vehicle structures and allied subjects.

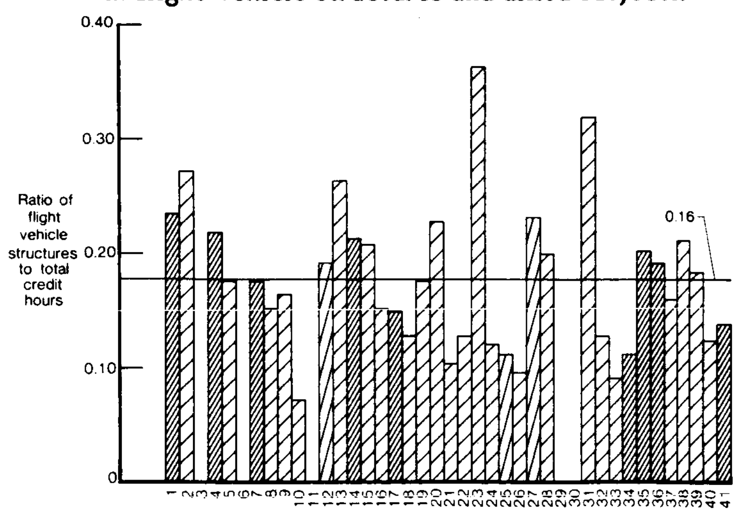
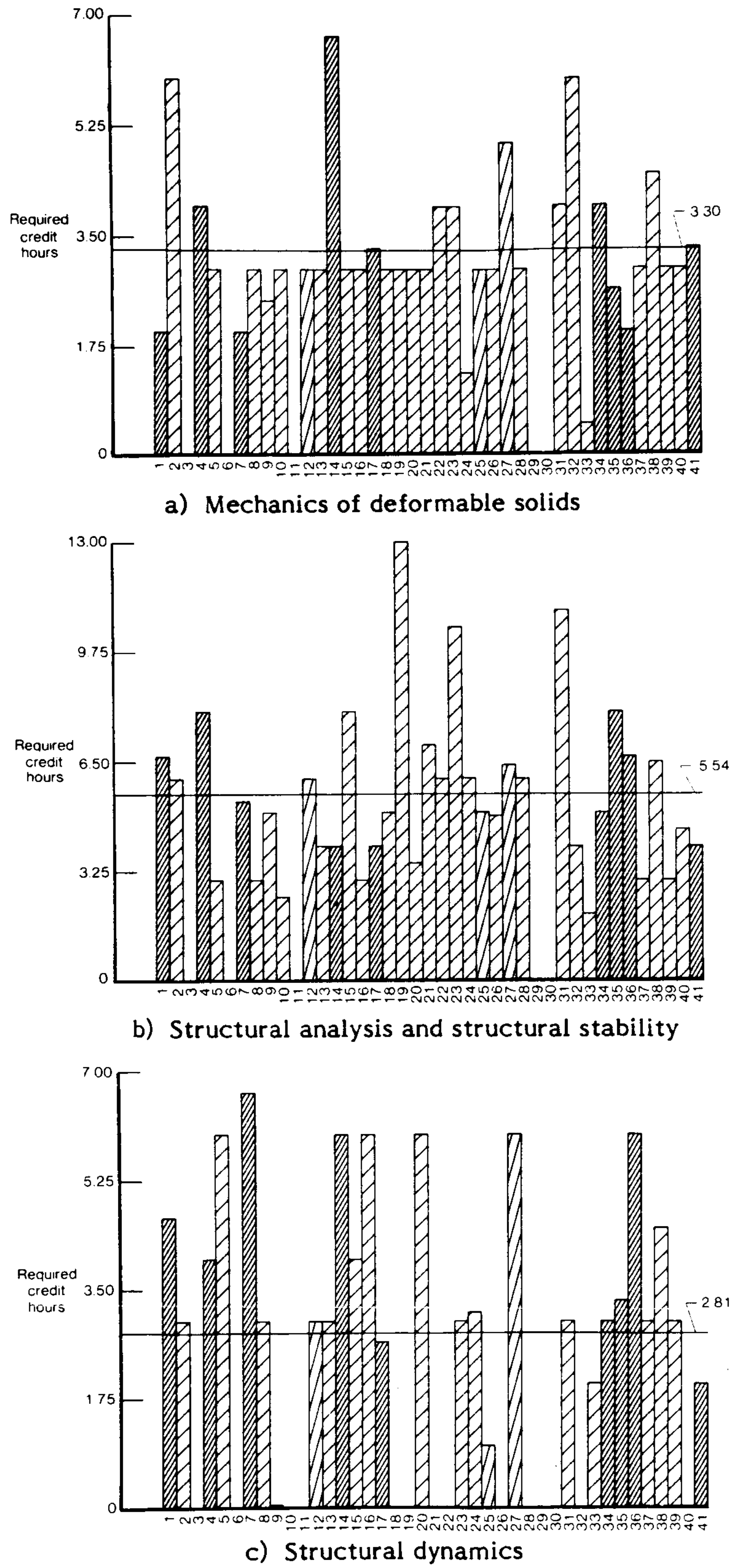


Figure 39 - Ratio of required flight-vehicle structures credit hours to total number of credit hours.

Quarter System
Semester System
Trimester System

1 Auburn University
2 University of Arizona
3 California Institute of Technology
4 California Polytechnic State University at San Luis Obispo
5 San Diego State University
6 Stanford University
7 University of California at Davis
8 University of Southern California
9 U.S. Air Force Academy
10 University of Colorado at Boulder
11 GWU (JIAFS)
12 Embry-Riddle Aeronautical University
13 University of Florida at Gainesville
14 Georgia Institute of Technology
15 University of Illinois at Urbana-Champaign
16 Purdue University
17 Tri-State University
18 University of Notre Dame
19 University of Kansas
20 Wichita State University
21 University of Maryland
22 U.S. Naval Academy
23 Boston University
24 Massachusetts Institute of Technology
25 University of Michigan
26 Mississippi State University
27 Parks College of St. Louis University
28 University of Missouri
29 Rutgers University
30 Cornell University
31 New York Institute of Technology
32 Rensselaer Polytechnic Institute
33 State University of New York at Buffalo
34 Air Force Institute of Technology
35 Ohio State University
36 University of Cincinnati
37 University of Oklahoma
38 Texas A&M University
39 University of Texas at Austin
40 University of Virginia
41 Virginia Polytechnic Institute and State University



Quarter System
Semester System
Trimester System

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6 Stanford University
7 University of California at Davis
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34 Air Force Institute of Technology
35 Ohio State University
36 University of Cincinnati
37 University of Oklahoma
38 Texas A&M University
39 University of Texas at Austin
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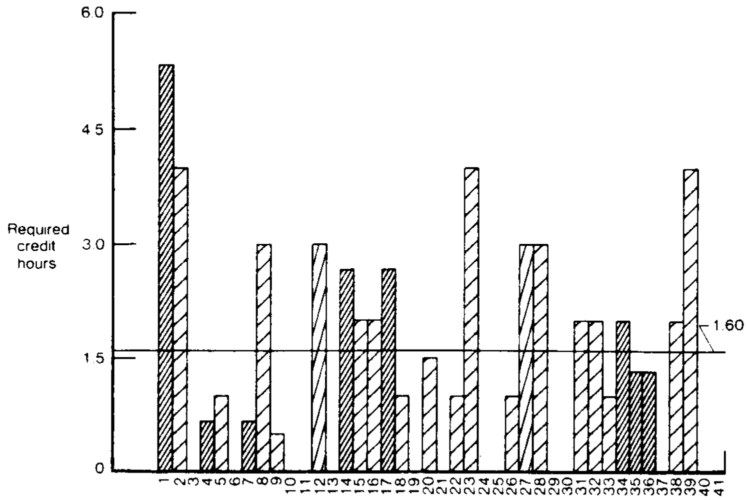
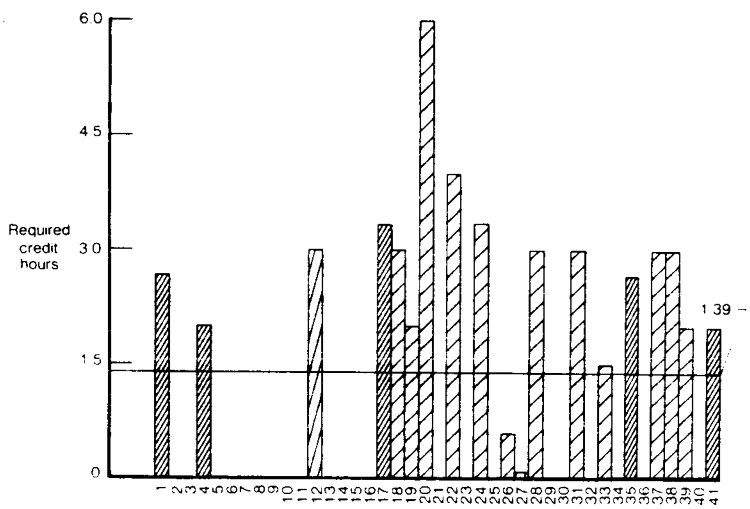
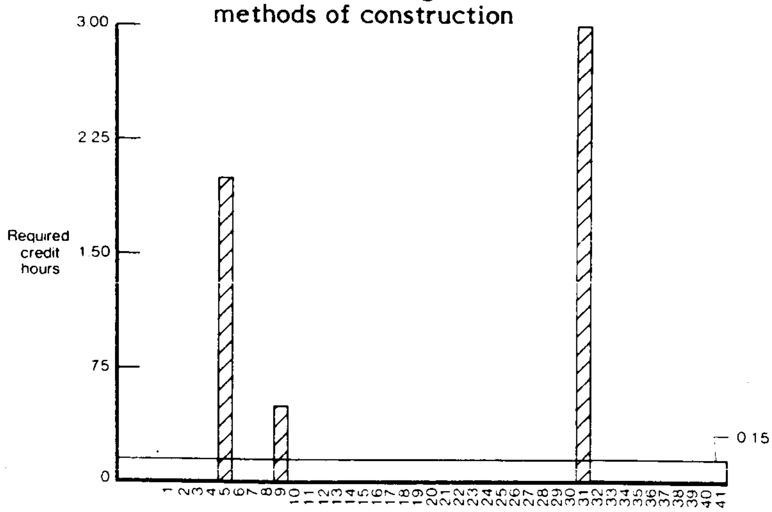
Figure 40 - Required number of credit hours in each of the subjects constituting flight vehicle structures.



d) Experimental stress analysis



e) Materials for flight vehicles and methods of construction



f) Aeroelasticity and aeroinelasticity

Quarter System
Semester System
Trimester System

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39 University of Texas at Austin
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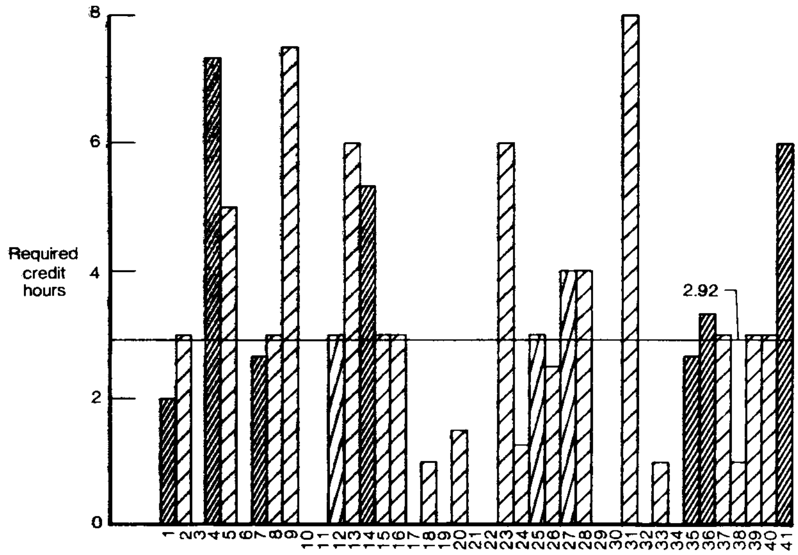
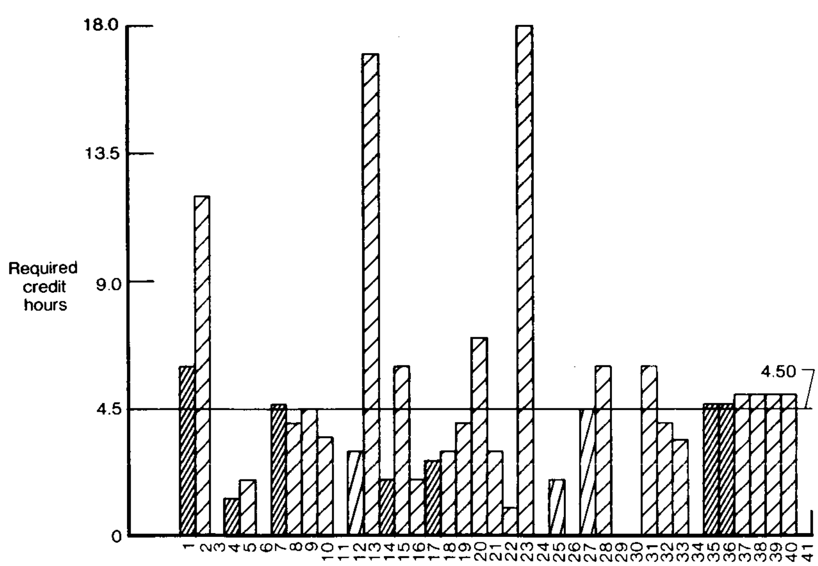
Figure 40 (Continued)



g) Structural design



h) Computational mechanics and CAD/CAM

Quarter System
Semester System
Trimester System

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Figure 40 (Concluded)

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15. Supplementary Notes

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16. Abstract

An assessment is made of the technical contents of flight-vehicle structures curricula at 41 U.S. universities with accredited aerospace engineering programs. The assessment is based on the technical needs for new and projected aeronautical and space systems as well as on the likely characteristics of the aerospace engineering work environment. A number of deficiencies and areas of concern are identified and recommendations are presented for enhancing the effectiveness of flight-vehicle structures education. A number of government supported programs that can help aerospace engineering education are listed in the appendix.

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